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STUDY OF PROFESSIONAL COMPETENCY DEVELOPMENT IN A PROJECT-BASED LEARNING (PBL) CURRICULUM

BY
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DISSERTATION SUBMITTED 2016

AALBORG UNIVERSITY
DENMARK

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Dissertation submitted

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CV

Bart Johnson is an active member of the engineering education community. His areas of focus are project-based learning, learning communities, professional identity development, and professional competencies. Currently, he is the Provost of Itasca Community College in Grand Rapids, MN, USA. Prior appointments at Itasca are dean of academic affairs, engineering program coordinator, and engineering faculty member. Through these roles, Johnson has been active in developing innovative engineering education approaches at the lower-division level in a community college setting and at the upper-division level with the Iron Range Engineering project-based learning program.

Outside of engineering, Johnson is professionally active with biomass energy initiatives and FIRST Robotics. He played a lead role in developing a woody biomass boiler project to bring a state of the art woody biomass boiler to the Itasca campus for applied research and increased academic programing within the engineering and natural resource programs. He is also a regional leader with FIRST robotics, a national program to provide an exciting hands-on experience to get K-12 students interested in and excited for STEM careers. He was recognized as the 2015 FIRST Robotics Volunteer of the Year for the Northern Lights Regional.

Prior to Itasca Community College, Johnson worked as an engineer for John Deere's construction and forestry division and was a research fellow for the Whirlpool Corporation.

ENGLISH SUMMARY

Engineers serve a vital role in developing technological solutions and innovations that meet societal needs. This is becoming even more evident as we experience rapid rates of change in technology and in the ways we live our lives. Accordingly, engineers no longer focus solely on technological solutions that are primarily based upon functionality and profitability; they develop comprehensive, complex solutions that include environmental, societal, ethical, and sustainability considerations.

Despite this change, how we educate engineers hasn't changed to the same extent. The approach remains primarily fixated on transmitting technical knowledge. While this approach provided a level of student knowledge and ability development that was appropriate at a point in time, that time has passed.

The expectations for practicing engineers have changed and so must engineering education if it and the profession of engineering are to play a lead role in society for current and future generations. Change is also needed to attract a more diverse group of individuals to the field of engineering, enabling it to better serve a diverse society.

A specific need in engineering education is the development of professional competencies. In the United States, ABET developed its a-k outcomes that included these professional competencies in 1997. However, little has changed in engineering education since that time. Looking to examples in other parts of the world, project-based learning (PBL) has been demonstrated as an effective approach to developing engineers, including their professional competencies.

This study looks at the adaptation of PBL to a new engineering program, Iron Range Engineering. Volume 1 advances the theoretical underpinnings of change, learning, curriculum, and PBL theories for the program development. It includes a detailed historical description of the curriculum and development process.

Volume 2 examines "in what ways does the PBL curriculum influence the development of professional competencies?" It includes a literature review and a description of the curricular approach creation to meet the professional competency development need.

The approach is based on developing professional competencies through cultivating the student professional identity with an emphasis on reflection and professional practice.

Both quantitative and qualitative studies are used. The quantitative study results indicate an increase in student professional competency performance ability through a pre- post- comparison and a comparative group study. The qualitative study identifies that the students experienced the development of professional competencies through reflection, self-identified continuous improvement, and positioning themselves in their professional competency ability.

The PBL curricular elements identified by study participants are authentic industry projects, professional competency learning activities, and the program culture. Some students experienced their commitment to professional competencies as a gradual process while others through a defining moment.

DANSK RESUME

Ingeniører spiller en afgørende rolle i udviklingen af teknologi og innovationer der opfylder samfundets behov. Dette bliver endnu mere indlysende, efterhånden som vi oplever hurtige teknologiske ændringer og de måder, vi lever vores liv. Derfor bør ingeniører ikke længere fokusere på teknologiske løsninger, der primært er baseret på funktionalitet og rentabilitet; de bør udvikle omfattende, komplekse løsninger, der omfatter miljømæssige, samfundsmæssige, etiske og bæredygtige overvejelser. Trods denne samfundsmæssige ændring, har måden hvorpå vi uddanner ingeniører ikke ændret sig i samme omfang. Uddannelser er fortsat primært baseret på at overføre teknisk viden. Hvor denne læringsform var tidssvarende på et tidspunkt, så rækker det ikke længere. Forventningerne til praktiserende ingeniører har ændret sig, og ligeledes bør ingeniøruddannelserne, hvis ingeniør professionen fortsat skal spille en ledende rolle i samfundet for nuværende og kommende generationer. Forandring er også nødvendige for at tiltrække en mere forskelligartet gruppe af individer til området for teknik. Kun derigennem gør det muligt at bedre at kunne betjene et mangfoldigt samfund.

Et specifikt behov i ingeniøruddannelserne er udviklingen af faglige kompetencer der kan anvendes i erhvervslivet. I USA har ABET i 1997 udviklet et sæt af læringsmål der omfattede disse professionelle og faglige kompetencer. Dog er der ikke sket store ændringer i ingeniøruddannelserne siden da. I andre dele af verden er der mange eksempler på ændringer, hvor bl.a. projektbaseret læring (PBL) har vist sig som en en effektiv metode til at uddanne ingeniører med relevante professionelle og faglige kompetencer. Dette studie fokuserer anvendelse af PBL i et nyt ingeniør program på Iron Range Engineering, USA. Bind 1 er baggrunden for studiet, hvor de teoretiske og organisatoriske rammer for forandring, læring, uddannelse og PBL teorier præsenteres. Det omfatter også en detaljeret historisk beskrivelse af uddannelsen og omstillingsprocessen.

Volume 2 undersøger "på hvilke måder påvirker PBL uddannelse udviklingen af professionelle kompetencer?« Det omfatter et litteraturstudie og analyse af uddannelsens tilgang møde behovet for professionelle kompetenceudvikling.

Den teoretiske tilgang baserer sig på læring af professionelle kompetencer og professionelle identitet med vægt på refleksion og professionel praksis. Der anvendes både kvantitative og kvalitative metoder i undersøgelsen. Den kvantitative undersøgelse viser en stigning i de studerendes faglighed præstationsevne gennem en præ- og post sammenligning og en komparativ undersøgelse af PBL-studerende og ikke PBL studerende. Den kvalitative undersøgelse viser, at de studerende har oplevet udviklingen af faglige kompetencer gennem refleksion, selv-identificerede

løbende forbedringer, og er i stand til at positionere deres professionelle kompetencer.

De deltagende studerende i undersøgelsen identificerer endvidere en række elementer i PBL uddannelsen som har været med med til at udvikle deres professionelle identitet. Dette er autentiske industri projekter, faglige og professionelle kompetence læringsaktiviteter, og programmets kultur. Nogle studerende har oplevet deres engagement i professionelle kompetencer som en gradvis proces, mens andre gennem et afgørende øjeblik.

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I thank my colleague, fellow PhD student, and good friend Ron Ulseth. This has been quite a journey since we started working together and the first conversation about the "academy".

Most of all I would like to thank my wife and children for their love, patience, and support while I committed my time and efforts to this work. Emma, Andrew, Mathew, and Gavin, I am looking forward to spending more time with you and not having to say to you "I've got to get some writing done first." Jess, I can't begin to express how much I appreciate your support and help through this process and as my partner and best friend in life. Thank you and I love you.

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FOREWORD

My entry into engineering education came after a period of time as a practicing mechanical engineer. I found many aspects in that part of my career rewarding and enjoyable, especially the mentoring and working with college students during their internships or as newly hired engineers. This resulted in my decision for engineering education to be part of my career path. My father had originally planted the idea in my head when I was working on my master's degree, but the desire to work with young people in starting their professional careers had become very real through this industry experience in working with students and new engineers.

When the opportunity came and I entered the field of engineering education, I was very much focused on helping students develop the professional competencies that I found many engineering students and recent graduates did not have when they came to work in industry. In fact the company, I was working for, at the time, had a 15-month program for new engineers to complete before they could continue as a full-status engineer. A major part of this program was about the development of their lacking professional competencies.

However, as I started my educational career, I found myself ill equipped with how to actually best help students learn in the academic setting. I found myself initially reverting to the same ways I had been taught as an undergraduate student. I knew lectures, extensive homework assignments, and a "token" group project were not the best way to do it, but I didn't know anything else. I spent most of my first few years using and trying to improve these very traditional approaches with results that I was not satisfied with in regards to their technical learning. My frustration was increased even more by the fact that they were learning very little of the professional competencies that had been my motivation to become an engineering educator in the first place. Something had to change!

The "Aha!" moment came for me when, with a group of colleagues, we read and studied two books from the National Research Council. The first, *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics* had the seven learning principles. It was a synthesis of the research in cognitive, learning, and brain sciences at the time. The second book, *How People Learn*, had a chapter on the designing of learning environments based on four perspectives on learning environments: Learner-Centered, Knowledge-Centered, Learner-Centered, and Community Centered. These book studies provided significant theoretical perspectives that truly began to develop my understanding about how people, students, learn and that the fundamental approaches that we were using in engineering education in the U.S. had to change. This began a period of innovation and development in engineering education that my colleagues and I began to pursue at the pre-engineering program we were at.

Great strides were made in growth of the program, student learning, and faculty development. However, most of this growth was through intuitive experimentation and adopting promising best practices through truly a practitioners approach without really seeking to understand why and how it worked. The motive was more towards finding what worked and just doing it. I found for the first time, that students were experiencing an education experience that they genuinely valued and was developing the professional competencies that had been a motivator for me.

The continued drive to improve student learning led to my involvement in the development of Iron Range Engineering (IRE), an upper-division, project-based learning program that was a continuation of the development work from the lower-division program. At the time, it was drastic departure from the accepted model for engineering education in the region of the U.S.

The practitioner's approach eventually reached a point of diminishing returns for me, in terms of improving the educational experience for students. At this point, the emphasis shifted to wanting to understand why and how something worked. My colleague and fellow PhD student, Ron Ulseth, and I found ourselves both wanting to transition from being just innovative engineering education practitioners to developing a deeper understanding of engineering education. In the develop of IRE, we had the fortunate opportunity to visit Aalborg University as a benchmarking activity and to have ongoing correspondences with Anette Kolmos and Erik de Graaff. Through a series of events, the opportunity arose to do this PhD study under them through Aalborg University. It was the perfect opportunity to develop my desired deeper understanding of engineering education and student learning.

Through this PhD study, I have started to understand engineering education and student learning in an entirely new way. The literature and theoretical frameworks have developed an understanding of student learning that allows me to understand why and how some of the curriculum work we had done in the past worked. It also provided new insight to why some curricular attempts did not work. Most important to me, it also provided new ways to improve the learning experience for students especially in regards to creating an authentic learning experience and developing the professional competencies of students.

During this PhD study, I have transitioned from being a faculty member through a couple of administrative positions. The new perspectives on student learning have allowed me to work across several academic disciplines and add value in guiding faculty in development of the learning experiences in their classes in a far more valuable way as a result of my PhD studies.

Coming full circle back to the passion of mine when I entered engineering education, professional competencies. This PhD study looks at the student development of professional competencies in the Iron Range Engineering PBL program. It has deepened my understanding of student development of professional competencies and, more importantly, is an opportunity for me to add to the body of knowledge in engineering education in developing them in the students of today for them to be the engineering leaders of tomorrow.

CHAPTER 1. INTRODUCTION

(BART JOHNSON AND RON ULSETH)

Currently in engineering education, there is a movement of change. It comes at a time when societies around the world are facing the challenges of the 21st century and beyond (www.engineeringchallenges.org). As with past challenges successfully met by societies, engineers need to be a crucial part of meeting these future challenges.

However, the nature of these 21st-century challenges is different than those of the past. “Engineering has to be seen in a very much broader context in terms of its role and impact on the society, and engineers need to have a very broad set of skills in addition to their engineering expertise” (National Academy of Engineering, 2005). Desha, Hargroves, and Smith (2009) identify that society also has a different expectation for engineers addressing these challenges that will require them to provide solutions that go well beyond just a technology focus and also involve “human values, attitudes, and behavior, as well as the interrelationships and dynamics of social, political, environmental, and economic systems on a global basis” (Splitt, 2003). This means that engineering education needs to adapt its model to graduate engineers ready for this new role.

This thesis is the result of the collaboration between two PhD candidates, Ron Ulseth, and Bart Johnson. Since 2010, we have been involved in the development and implementation of the new Iron Range Engineering (IRE) program, a program that emerged as a result of the calls for change. The IRE program started as an adaptation of the Aalborg model of engineering education and consists of the third and fourth upper-division years of an engineering bachelor’s degree. The IRE model is based on student attainment of technical, professional, and design competencies while working on industry projects. IRE started accepting students in January 2010. At the time of this PhD defense, 95 students had successfully completed the degree and 60 additional students were currently making satisfactory progress towards degree completion. The IRE model is ever evolving. It is the product of an engineering educator practitioner’s approach to curriculum development. It has been successful in the sense that students are readily received by industry as valuable members of the profession. The program received initial accreditation by ABET. However, for the IRE program to continue to improve and viably develop its ability to impact engineering education, its development process, and the current educational model need to be evaluated and improved from an engineering education researcher’s approach. Our goal in the PhD experience was to gain the research perspective to bring to bear on the IRE program.

Within this context, each candidate developed an individual research program. Of particular interest to Johnson was the development of professional competencies by students. Ulseth chose to investigate the impact on students' attainment of self-directed learning (SDL) abilities. Thus, the two research studies to be undertaken were:

1. Mixed-methods explanatory study of the professional competency development by PBL students. (Johnson)
2. Mixed-methods study of the self-directed learning experience of PBL students. (Ulseth)

One of our motivations was to apply change, curricular, and learning theories to analyze the development and implementation of the IRE model. We desired to understand our experiences of success and failure as viewed through the perspectives of theory, something that was not done during the development and initial implementation. We worked closely together to write the first volume. This collaborative work analyzes the Iron Range Engineering model. The analysis starts with a theoretical perspective on the aspects of change, curriculum, learning and PBL (Chapter 2). The perspectives are then used to detail how the Iron Range Engineering program came about (Chapter 3 – History) and to describe the details of the model (Chapter 4 – Iron Range Engineering).

Johnson's thesis includes the shared Volume 1 and his own Volume 2 covering the professional competency development study. Ulseth's thesis includes the shared volume and his own Volume 2 on self-directed learning.

1.1. CALLS FOR CHANGE

In this volume, we analyze the theories used in the development of the Iron Range Engineering program. Presented first is the context in which the Iron Range Engineering program was developed with a focus on why the need for change, what is required from a new model of engineering, and how it can be achieved.

The need for change resulted from the recognition of engineering education being at a crossroads. Does it continue down the current path or change course to respond to the calls for changes (Graham, 2012b)? Making this decision requires knowing what are the calls for change and what can be achieved by heading down the new path.

On a global level, UNESCO commissioned and released two important reports: *ENGINEERING: Issues, Challenges, and Opportunities for Development* in 2010 and *Engineering Education: Transformation and Innovation* in 2013, to focus attention on making engineering education "more interesting and relevant at a time of changing global need, issues, and contexts" (Beanland & Hadgraft, 2013). The reports emphasize the importance of engineering and engineers for providing the technological developments needed by society. At the same time, they identify the undersupply of engineering graduates in countries around the world and the very low percentage of formal graduates, which is creating substantial gaps, in most countries, between the number of graduating engineers and the number of engineers required to meet their nation's needs. The need for promoting engineering and engineering careers to the public to create greater awareness of the importance of and career opportunities provided in the engineering field is clearly evident.

Nationally, research and study findings in Australia, the U.K., and the U.S. are also expressing concerns over an insufficient supply of engineering graduates who are equipped to meet the current and anticipated needs (Institution of Engineers, Australia 1996, Royal Academy of Engineering 2007, Engineering, 2005). One identified step to overcoming this shortage is shifting student perceptions of engineering towards finding it as an exciting and rewarding profession that is worth pursuing. Additionally, they also identified the need for universities, and industry, to make engineering education content align more closely with the actual professional practice of engineers to equip graduates with the competencies and attributes necessary for practice.

There is an evident concern for the widely held view that "many contemporary engineering graduates are deficient in the capabilities that are required of engineers" (Kolmos, 2013). A gap exists between engineering education and the current and future needs of the engineering profession. This global situation has led to international calls for transformative change in engineering education. The 2010 UNESCO Report on Engineering: Issues, Challenges, and Opportunities notes that:

> "One of the greatest challenges for engineering is the need to make engineering education more interesting and relevant at a time of change in global needs, issues and contexts, such as the rising concern regarding climate change, and the opportunities provided by information and communication technologies in engineering and engineering education. There is a particular need for the university and other courses to be reviewed in terms of the appropriateness of the desired outcomes, the effectiveness of the learning and teaching approaches, and the appropriateness of the curricula. It will be suggested that it is possible to emphasize the development of engineering skills and expertise through a problem-solving approach with application to address both local and global issues such as poverty reduction, sustainable development, and climate change mitigation and adaptation."

The follow-up 2013 UNESCO Report, Engineering Education: Transformation and Innovation, identifies that educational institutions will not accomplish this by themselves. The elements necessary for this change will need to come from external stakeholders (Beanland & Hadgraft, 2013), including:

- Major Engineering Employers
- Professional Organizations
- Governments

In the United States engineering education system, these three stakeholders have joined to make several extensive calls for engineering education to create a new model of engineering education, including:

- National Academy of Engineering's "The Engineer of 2020" (2004)
- National Academy of Engineering's "Educating the Engineer of 2020" (2005)
- National Science Board's (2007) "Moving Forward to Improve Engineering Education

These calls focus on the societal needs for a "new look" engineer and they address that the engineering education model needs to transform the engineering curricula from engineering content knowledge transmission to the "development of skills that support engineering thinking and professional judgment" (Adams & Felder, 2008). Such a redesign of engineering curriculum requires a focus on the product that it produces and a significant shift away from the current status of the inward focus on the organization of the engineering education curriculum itself, as so many engineering education improvements have been focused on, to date, in the U.S., and around the world.

In Europe, the Bologna Process emphasizes the importance of improving engineering graduates' competencies in innovation and entrepreneurship (Communiqué, 2009). The Royal Academy of Engineering (Spinks, Silburn, & Birchall, 2006) study of "Educating Engineers for the 21st Century" also makes several findings regarding the need for transformation of engineering education including:

- Universities and industry need to find more effective ways of ensuring that course content reflects the real requirements of industry and enables students to gain practical experience in industry as part of their education.
- Much more needs to be done to ensure that school students perceive engineering as an exciting and rewarding profession that is worth pursuing.
- Unless action is taken, a shortage of high caliber engineers entering industry will become increasingly apparent over the next 10 years

> with serious repercussions for the productivity and creativity of industry.

A significant step identified by the international community to eliminate the gap between educational and industry expectations for engineering students commenced in 1989 with the professional organizations and institutions from Australia, Canada, Ireland, New Zealand, United Kingdom, and the U.S. forming what would become the Washington Accord. Several countries from around the world have since joined it (Beanland & Hadgraft, 2013).

The Washington Accord sought to establish standards for professional competencies and develop attributes of engineering students graduating from an accredited institution. Specifically, it creates a competency focus for engineering education and broadening the focus of engineering education to include preparation for professional practice. Lemaitre, Prat, Graaff, and Bot (2006) confirm that the preparation "of students for professional competence has always been the ultimate goal of engineering curricula."

In the U.S., the Washington Accord led to ABET, the non-governmental accrediting body for the U.S. engineering education system, introducing a new set of engineering accreditation criteria, ABET Engineering Criteria 2000 (Abet.org, 2015). Of greatest significance to changing engineering education was the General Criterion 3 student outcomes, also known as the ABET Criteria. This set of outcomes reflected a movement in the U.S. towards a focus on the student development of their professional competencies and attributes. Similar movements were taking place in other countries around the world. In the United Kingdom, the application of the Washington Accord was through the Engineering Council UK. In Australia, Engineers Australia established the competency standards.

It is evident that the time has arrived for engineering education to go beyond the current state of focus on cutting-edge technology and increasing knowledge acquisition, and move toward an equal focus on all aspects of engineering practice and scholarship (Denning, 1992; Goldberg & Somerville, 2014; Pister, 1993; Prados, 1998; Splitt, 2003). Satisfying the demand for change within the current traditional curriculum will be very difficult, if even possible (Fromm, 2003). A new paradigm, a new model, in engineering education is needed.

1.2. REQUIREMENTS OF NEW MODEL OF ENGINEERING

This need for a new paradigm is generating much discussion about what should be the "nature, context and curricula of undergraduate education" (UNESCO, 2010). This dialogue is influenced by the rapid expansion of knowledge, changes in engineering practice, concerns for attracting adequate numbers of students into the engineering profession, and change requirements of employers. While the need is evident for transformation of engineering education to match the changes in the engineering profession, very few have actually changed to a new instructional model. In the U.S., Walther and Radcliffe (2007) identified that despite the interest by universities and engineering faculty throughout the U.S. in changing to meet the needs of the profession, the engineering education system is still not providing graduates with the competencies identified as needed by industry.

In *Educating Engineers: Designing for the Future of the Field*, a study of engineering programs at several U.S. institutions also identified that not much has changed in the engineering education system regarding the design of the curriculum to meet the professional competency needs of the engineering profession (Sheppard, Macatangay, Colby, & Sullivan, 2009). Study results indicate, "undergraduate engineering education in the USA," and in most other parts of the world, "is holding on to an approach to problem solving and knowledge acquisition that is consistent with practice that the profession has left behind." It found that the engineering curricula were still heavily biased towards analysis to the detriment of professional skills development as well as other areas of engineering.

Of further concern is noted by van der Vleuten (1997) that often as change is attempted, faculty appear to use intuition as the approach to improving teaching and student learning instead of using a scientific approach. Most educational experiences are still based on an assumption that the development of professional competencies can occur in a set of discrete finite episodes with a beginning and end (Wenger, 1998). This is despite the fact that students and employers, alike, expect a higher degree of synergy between what is learned in the classroom and what is needed in the field (Passow, 2012).

Goldberg and Somerville (2014) provide three lessons from the history for engineering education as transformation is sought. First, the change that is needed cannot be accomplished with small changes to existing curriculum. Second, students are "sensitive to the their world of work and to the culture of the education system." In agreement with Passow, a high degree of synergy is needed between the engineering education experience and the profession. Third, change management attempts to date have not been successful. New bold approaches are needed to accomplish the change.

There is growing concern that the continuation of the old paradigm of engineering education will not only not prepare graduates to meet these challenges, but will also lead to engineers being relinquished to minor roles in meeting the 21st-century challenges facing society (Splitt, 2003). The 2013 UNESCO Report on "Engineering Education: Transformation and Innovation" (Beanland & Hadgraft, 2013), states that

> "It is widely acknowledged that engineering education requires a transformation to produce graduates, in sufficient numbers and with appropriate knowledge and skills, to proved the capabilities to address the many technological issues and projects at are required for the development of our communities."

The report outlines a vision for the key steps or principles for transforming the "design and implementation of an effective engineering curriculum":

- The first step towards Transformation is the adoption of the Washington Accord Graduate Attributes as the goals of each engineering education program to be realized by every graduate.
- The second step towards Transformation is to design the curriculum to maximize the development of the capabilities that are essential to operating as a professional engineer.
- The third step towards Transformation is the design and implementation of the first year of the engineering education program to maximize student motivation.
- The fourth step towards Transformation is the utilization of Project-Based Learning in each year of engineering education programs.
- The fifth step towards Transformation is the replacement of the information transmitting lecture in engineering education programs with activities that generate student-centered learning through the active involvement of students, which creates thinking, aimed at developing understanding.
- The sixth step towards Transformation is the utilization of the wide range of Information Technology and Communication Systems and resources to facilitate student-centered learning.

A similar guiding strategy for curriculum improvement is provided in *Educating the Engineer of 2020* (National Academy of Engineering, 2005). It proposes that effective improvements for engineering education in the U.S. must focus on the whole educational system and move beyond the current ineffective approach of incremental improvements to single aspects of complex curriculums. The publication promotes a systems level educational approach that, at a minimum, incorporates the following elements:

- Application of engineering processes to define and solve problems using scientific, technical, and professional knowledge bases
- Engagement of the engineer and professionals from different disciplines in team-based problem-solving processes
- Tools used by the engineer and other technical professionals
- Interaction of the engineer with the customer and engineering managers to set agreed-upon goals;

- Economic, political, ethical, and social constraints as boundary conditions that define the possible range of solutions for engineering problems and demand the interaction of engineers with public" (National Academy of Engineering, 2005)

Rompelman and De Graaff (2006) also proposed that engineering education curriculum should be developed from a systems approach. In the systems approach, they propose that an educational process is one that transforms students from their the state of their initial attributes as they enter an engineering program to a state of graduate attributes as they complete the education process. The proposed premise is that the learning process is one where the learner "constructs knowledge on the basis of prior knowledge and additionally acquired information." This process is based on a constructivism perspective (Jonassen, Pfeiffer, & Wilson, 1999).

1.3. ACCOMPLISHING CHANGE

Achieving a system level educational change is difficult to accomplish (Kotter, 1995) and represents a significant departure from the current model of engineering education around the world and especially in the U.S. It is a difficult process to transform the complex and diverse system that engineering education is with its large number of variables (Beanland & Hadgraft, 2013). Even more difficult is maintaining the change once it is accomplished (Graham, 2012b).

In the Royal Academy of Engineering and MIT commissioned report, Achieving Excellence in Engineering Education: The Ingredients of Successful Change (Graham, 2012a), identifies the pressing issue for engineering education, is not whether to change, but how to change. In its two-stage study of successful change, three common features were identified for the designing of successful programs of change.

First, successful change requires it to be about the entire curriculum structure. The new structure must be interconnected and coherently support the change being attempted. Second, successful change requires the curriculum structure be developed with curriculum goals in mind by the entire cross section of faculty. Graham notes that this part of the curriculum design is necessary regardless of the scale involved with the change. The Third, successful program changes are ambitious and aspire to develop a new "brand for the education approach." The aspect of creating a national or international education model is a motivating factor in engaging the faculty to create and sustain the change.

Committing to such a significant level of change in the development of the new curriculum for this research work requires a curriculum development process that is framed within the context of both the state of the art for curriculum theories and the state of the art of learning theories. The magnitude of the change, in developing a new engineering curricular approach, requires the curriculum development to be framed within change theory. These will be developed in Chapter 2.

1.4. PBL IN CALLS FOR CHANGE

The report by 2013 Graham and the UNESCO reports identify PBL as an integral part of successful curricular changes and as one of the key steps in the "design and implementation of an effective engineering curriculum," respectfully. Graham's study revealed that a majority of the highly regarded examples of change involved the use of PBL within an "authentic, professional engineering context." Project-based learning is a core theme throughout the 2013 UNESCO report to achieve the Washington Accord graduate attributes and to provide the "personal learning experiences" needed for the transformation of engineering education. It identifies that,

> "Project Based Learning (PBL) is a widely reported approach to address the need to change engineering education, from the formal presentation of technical material to a student experience model. It provides activities, which simulate the role and responsibilities of practicing engineers, and develops the general graduate attributes that have been identified as essential. It was first used in medical education and is now extensively used as it promotes the development of the skills and knowledge required by medical practitioners… Project Based Learning can be organised for individual work, but there is greater benefit from having the project under- taken by a team of students. This relates more closely to a realistic engineering environment, provides an opportunity for students to learn from each other, and assists the development of the essential graduate attributes of team- work and leadership."

The Cambridge Handbook of Engineering Education Research is a new reference source for the "growing field of engineering education research" (Johri & Olds, 2014). The book focuses on five key themes identified by the U.S. National Science Foundation and published in October 2006 in the *Journal of Engineering Education.* The second section of the handbook, "Engineering Learning Mechanisms and Approaches," focuses on approaches for transitioning from traditional to a variety of active student learning approaches in engineering education. This section begins with an explanation of problem-based and project-based learning models by Kolmos and de Graaff as an example of the curricular approaches engineering education should be considering.

Throughout the engineering education literature, it is evident that PBL should be strongly considered in the development of a new, or the change of an existing, engineering program. In the development of this new program, PBL and PBL theory are an integrated core component of the curricular model.

1.5. DESCRIPTION OF IRON RANGE ENGINEERING

Using the perspectives of change theory, curricular theory, learning theory, and PBL theory, which are presented in Chapter 2, the program is first presented in its historical context (Chapter 3). Then the current model of the program is thoroughly detailed through the inclusion of its curricular makeup, pedagogical approaches, space considerations, and its people (Chapter 4).

1.5.1. OBJECTIVES

1. Describe the motivations behind the start of the Iron Range Engineering program.
2. Describe the Iron Range Engineering program through theory.
3. Explain the evolution of the Iron Range Engineering.
4. Show how the curricular elements of the Iron Range Engineering model are implemented.
5. Detail how the Iron Range Engineering program implements the principles of PBL.

1.5.2. BACKGROUND

In 2010, the new model of project-based learning began in the iron-mining region of Minnesota in the United States. This program was adapted from the Aalborg University model of PBL in Denmark. At the time, curricular level PBL in engineering education in the U. S. was rare. The program developers were motivated by the calls for reform in engineering education to better align educational experiences and outcomes with expected competencies needed in engineering practice.

Embracing core values of continuous improvement, professional responsibility, the power of reflection during learning, industry-sponsored projects, and self-directed learning, the implementation team began the new model of PBL. This model became a social construct of the students, professors, industry clients, and communities.

The development and implementation teams faced adversity on many fronts as the new model strove for acceptance in the engineering and academic communities. That acceptance slowly arrived as graduates found success in their positions and the program attained ABET accreditation.

1.5.3. ANALYSIS FRAMEWORK

Volume 1 is an analysis of the Iron Range Engineering program bounded on one end by the inception of its existence and the other by the completion of the PhD studies. The Iron Range Engineering PBL program is analyzed from three distinct perspectives: theoretical, historical, and descriptive. Chapter 2 develops the theoretical perspective for the aspects of change, curriculum, learning and project-based learning that were applied in the development of the program. These theoretical aspects are used in Chapters 3 and 4 to analyze the program. Chapter 3 develops a historical description of development and analyzes this process in relation to the change theory. Chapter 4 describes the current program and provides a descriptive analysis within the theoretical framework of curriculum, learning, and PBL.

At the conclusion of Volume 1, the results of this analysis will be presented. The results will include a set of key findings for consideration by engineering education and those individuals involved with curricular change decisions. Throughout Chapters 3 and 4, these key findings will be highlighted as they are first identified.

In addition to literature review resources used in Chapter 2, a variety of data was available for developing the analysis for Chapters 3 and 4. First, was the abundance of printed documents in the forms of syllabi, student handbooks, and faculty handbooks from each of the years of the program's existence. The documentation for the current program description was collected from the program directors in the forms of syllabi, faculty and student handbooks, the program website and wiki, through access to a wide set of documents on their shared document collection.

Second, there was a large set of published materials available: materials from members of the development team longitudinally while the program was being created, initially implemented, and achieving a steady operating state; materials published by the current program personnel and media publications written about the program. These artifacts are available from the beginning of the idea, to the present time.

Third, the personal accounts of the researchers' direct observation were also employed. The researchers lived through the entire evolution of the program as members of the initial development and implementation teams. Ulseth has observed the daily implementation of the program throughout its entirety.

Attempts have been made to mitigate any bias through the use of artifacts to substantiate all descriptions. Member checking by having other members of the development and implementation teams was employed to reduce this bias by having them read the descriptions checking for accuracy and varied perspectives. The situation of having two researchers in this study also provided the opportunity for frequent peer checking of facts and processes. These iterative discussions added substantially to the depth of the analysis as well as in the elimination of errors. The data is presented in deep detail in an attempt to achieve a rich description.

1.6. CONCLUSION

It is at the intersection of our personal motivations, the widespread calls for change in engineering education, and the implementation of the Iron Range Engineering program that this PhD work begins and ends. This intersection represents the themes present in this undertaking: 1) the development of us as individuals from being reflective practitioners to being both practitioner and emerging researcher, 2) the opportunity and obligation to contribute new knowledge to engineering education, and 3) a desire to use new found knowledge to continuously improve the Iron Range Engineering model of learning.

This section is written after all other chapters are in draft form. The PhD process has been successful in transforming us as individuals. For our combined 35 years in academia, we have been active, innovative, and reflective practitioners with the perspective for the opportunity and passion to improve engineering education. The PhD process has significantly broadened this perspective and allowed us to be able to reflect and analyze in an academic way, to include theory and research, our work.

This process of growth comes with struggles to begin to think like researchers and to write like academics. The patience and guidance of Anette Kolmos and Erik de Graaff allowed the transformation to begin and to progress. We are thankful for this opportunity to continue our work with engineering education now empowered more as academics.

As alluded to in Section 1.3, the calls for change in engineering education have existed for decades and have gone largely unheeded. The motivations for starting Iron Range Engineering were rooted in the desires to design and implement a curriculum that better aligned with the needs of the profession and contributed to the development of engineering education.

The first six years of the curriculum's implementation yielded experiences and results that, when properly disseminated, provide knowledge for others to consider. The knowledge themes of potential value include the change process experienced during startup, the unique approaches taken to align with the professional competence needs of the profession, the model of continuous improvement embraced by the program, the developmental trajectory taken by the program, and the metacognitive and reflective development of the self-directed learners.

At question is whether this research should be conducted externally by those who had no part in the program's operation, or internally by those who lived the experience. We believe the answer is both, that each perspective has potential value. As people who lived the experience, we did do the research in our PhDs. At the time of the PhD defenses, two additional, external research projects on these topics are in progress. Thus, substantial steps are being made, in attempts to meet the obligation of contributing new knowledge to academia.

CHAPTER 2. THEORETICAL PERSPECTIVE

(BART JOHNSON AND RON ULSETH)

The description of the IRE program, it development, and analysis starts with a theoretical perspective on the aspects of change, curriculum, learning and project-based learning. Each of the aspects will be developed in its own section. Each section will conclude with the applications from the theoretical perspective to be used in the description, development, and analysis of the IRE PBL program.

2.1. CHANGE THEORY

> "Good ideas with no ideas on how to implement them are wasted ideas"
> (Fullan, 1982)

With such widespread agreement for the need to transform engineering education, why is there, then, an apparent lack of response from engineering universities to transform to meet this need? (Beanland & Hadgraft, 2013; Graham, 2012a, 2012b; Singer, Nielsen, & Schweingruber, 2012). One key part of this question is how to develop a successful process of change to respond.

In developing the Royal Academy of Engineering and MIT commissioned report, Achieving Excellence in Engineering Education: The Ingredients of Successful Change, a two-stage study of successful changes in engineering education was conducted (Graham, 2012b). In the first stage, interviews of 70 international experts from 15 countries were conducted to provide insight into curriculum change. The second stage was focused on 6 case examples, with an additional 117 individuals interviewed to further understand the curricular change. This study, led by Ruth Graham, identified common strategies for successful change that can be summarized in three phases:

> Phase 1: Preparatory Work – This consists of first gathering local evidence for the need for change, and then benchmarking other educational approaches. This is followed by generating an early broad vision for change, first to senior management and then to faculty. This is a critical step in the process of gaining the support of leadership and faculty and requires an emphasis on the change and the drivers for change. It is important not to look at a solution first; otherwise the focus shifts to the personal impact on each of these individuals and thus diverts away from the solution.

Phase 2: Planning for the Change – once the decision has been made for changing, the "underpinning educational approach" that is unique to the institution should be determined. Then faculty involvement in a blank slate approach to a new curriculum design is critical for optimizing support for the change.

Phase 3: Implementing the New Approach – an implementation team of respected individuals should be released from other duties to focus solely on the implementation of the new approach. Key aspects identified in the study for implementation success included frequent demonstration of benefits to students and faculty involvement with the new approach. The implementation speed and phases varied in the study, but all changes were implemented in a "single, concentrated effort over a two – four year period and called for considerable faculty-wide attention during that period." Reform changes all took at least five years to implement.

It is apparent that the transformation of engineering education must be viewed as a process and not as an event (Fullan, 2001). Given the complexity and the difficulty of successful change processes (Blackmore & Kandiko, 2012) and that less than 35% of change efforts produce enduring, significant change in the operation of an organization (Kotter, 1996), a change model is necessary to view the development of this program. In this section, a framework for the change, which is modeled around the Froyd et al. (2000) "Organization Change Model" based upon the Kotter (1995) eight-step model for organizational change, is presented. The model includes the work of de Graaff and Kolmos (2007) and Daft (1978) regarding a dual focus on curriculum and organization in the change process.

2.1.1. ORGANIZATION CHANGE MODEL

Froyd, et. al., (2000) proposed the Organization Change Model as a model to transform undergraduate engineering education It focuses on organizational change and is based upon the eight-step change model developed by Kotter (1995). Table 2.1 shows the parallel steps for the Froyd and Kotter models.

Table 2.1. Organization change model

Froyd	Kotter
Establish need and energy for a curricular change	Establishing a Sense of Urgency
Gather a leadership team to design and promote the curricular change	Forming a Powerful Guiding Coalition
Define and agree upon new learning objectives and a new learning	Creating a Vision

environment	
Discuss the new objectives and environment with the college and revise based on feedback	Communicating the Vision
Implement new curriculum using a pilot, if necessary	Empowering Others to Act on the Vision
Conduct a formative evaluation of the program, investigating strengths and weaknesses of the current implementation, and indicators of short-term gains	Planning for and Creating Short-Term Wins
Decide how the new approach may be used for the entire college, and prepare an implementation plan	Consolidating Improvements and Producing More Change
Prepare faculty and staff for the new implementation, implement, and follow up with improvements	Institutionalizing New Approaches

The Organization Change Model primarily focuses on “changing people’s attitudes toward ongoing curriculum change and equipping them to continually change. Its focus is on people rather than validity” (Froyd et al., 2000).

In this Organizational Change Model, “the underlying assumption is that the need for change must be well established and nurtured before the rest of the process can succeed (Froyd et al., 2000). Establishing the need for change is a very important step in the change process. The literature on change contains many references to this. Kotter (1995) identifies allowing too much complacency as the first error causing organizational failure and identifies creating a sense of urgency as the first step in a successful change process. It is critical that the sense of urgency be recognized at all levels within the organization.

Kezar’s (2001) six categories for change also focus on the urgency for change and are based on a “distinct set of assumptions about why change occurs.” The strategies all focus on what causes people and education institutions to change, and then use that information to guide the change process. In Graham’s Royal Academy of Engineering and MIT commissioned report, Achieving Excellence in Engineering Education: The Ingredients of Successful Change (Graham, 2012a), the first common feature of successful programs of change is that it requires it to be about the entire curriculum structure and created interconnectivity across the structure of the program. This requires the entire organization to recognize the urgency and to coherently support the change being attempted.

In the development of the Organization Change Model, Froyd (2000) gives three reasons for establishing the need and energy for change, the urgency. First: addressing the question "why change?" and also identifies that getting others to join in the sense of urgency is critical to gaining support for the change. Second: faculty members need to believe the innovation will be successful before bringing it to the classroom. They have great influence over students' motivation, which is critical to a successful change process. Third: as faculty members embrace the change, they "may spontaneously work to improve their learning environments." Identifying the drivers for creating this urgency and establishing the need and energy for change is a critical first step in the change process. "Change in learning will only occur if there are both external and internal drivers" (Kolmos, 2013).

The second step in the change process is forming a leadership team and promoting the curricular change. This guiding coalition will need to include members of all levels at an institution: administration, faculty, and staff who are convinced of the need, as well as the skeptics. Kolmos (2013) also highlights the inclusion of individuals from all levels to create a top-down and bottom-up approach as a critical part of creating adequate internal drivers and core change agents. Additional engineering education literature supports the combination of top-down and bottom-up approaches for successful educational change (de Graaff & Kolmos, 2007; Heywood, 2006; Seymour, DeWelde, & Fry, 2011; Walkington, 2002). Berglund, Ritzén, and Bernhard (2014) identify the need for a balance support of the change between the two approaches. In their review of organizational change, they identify the increased sustainability of change when it is accomplished through a wide, program-level context. Kolmos (2013) also identifies that importance of educating the core change agents and the potential for inspiration by engaging other regional and international education communities in the process.

Steps three, four, and five focus on vision casting and communicating, and then empowering people to act on that vision. Fullan (2001) and Moesby (2004) identify vision and consensus as key internal drivers needed for successful change, and yet they are often missing in most engineering educational changes (de Graaff & Kolmos, 2007). Three of Kotter's (1995) eight reasons for firms failing involve vision:

- Underestimating the power of vision
- Under-communicating the vision by a factor of 10 (or 100 or 1000)
- Permitting obstacles to block the new vision

Froyd's model identifies that vision creation, communication, and implementation all need to focus on curriculum development in the engineering education change process. It is imperative that the vision is supported by, and addresses, the drivers for change. It is not adequate for the vision casting and communication to come from just one level of the organization, empowering people to act means empowering people at every level of the organization. Graham (2012a) identifies the importance of "strong leadership with a clear and well communicated educational vision" as one of the key features of successful change. In discussing this, Graham quotes both Kezar (2009) "one of the main reasons that changes do not occur is that people fundamentally do not understand the proposed change and need to undergo a learning process in order to successfully enact the change" and Seymour et al. (2011) regarding the importance of "radicalized seniors" serving as key champions in the change process "in publicly promoting educational improvements, legitimating their uptake, protecting younger faculty reformers from negative consequences of their work, and using their power and influence to leverage change at the national, institutional, departmental, and disciplinary levels."

De Graaff and Kolmos (2007) also identify the need for all levels of the organization to be involved if the change is going to be successful. Both a top-down and bottom-up strategy must exist such that the different organizational level efforts are complementing one another in developing a common vision. Ownership at all levels is necessary for all levels to be drivers for change (Kolmos, 2013). Engaging all levels of the organization is about creating a sustained institution movement. Change is a process, not an event (Fullan, 2001).

The initial vision will need to be evaluated and improved upon in an iterative process. The sixth step is about the formative evaluation of the new curriculum with the purpose of understanding what needs to be improved and, equally important, celebrating what are the initial successes. Doing so will address two of Kotter's (1995) other reasons for firms failing. First, they fail to create short-term wins to keep people excited about and engaged in the new curriculum, and secondly, they declare victory too soon, which would allow complacency from some individuals to see, and for the naysayers to be able to point out, its shortcomings before the model is fully developed. Again, the change process is about creating a sustained institutional movement.

Steps seven and eight are about anchoring the change in the culture of the institution. This is a critical step in the change process (Kotter, 1995). Froyd's, (2000) premise for the model is about "changing people's attitudes toward ongoing curriculum change and equipping them to continually change." It is important to not only make this change part of the culture of the campus, but it is more important to use this process to create a culture focused on continual positive change. Graham (2012a) identified that the successful program changes in her study are ambitious and aspire to develop a new "brand for the education(al) approach." The aspect of creating a national or international educational model is a motivating factor in the engaging the faculty and creating a sustained institutional movement.

In summary, Froyd's Organization Change Model provides a model for the transformation of an engineering educational curriculum at an institution by focusing on changing peoples' attitudes and creating a culture of change. Utilizing this model requires an understanding of what the focus will be in the vision for the engineering education curriculum change process to developing the sustained institutional movement.

2.1.2. CURRICULUM MODEL FOR CHANGE

Daft's (1978) work on organization change led to the dual-core model of organizational innovation which recognized the need for both a technical and an administrative core in the focus of the change process. The technical core is the operational level of an organization, which, in education, would parallel the curricular level of focus for development. The administrative level in an educational institution includes the structure, policies, procedures, and culture created by the campus leadership.

De Graaff and Kolmos (2007) in "Management of Change" introduce a curriculum model for engineering education that identifies relevant elements for a successful change. It is based on findings and works of Him and Hippe (1993) and Kolmos (2002) with relationship didactics modeling. Like Daft's model, it focuses on two layers, the curriculum layer and the organizational layer. The *curricular layer* is focused on six elements: 1) students, 2) teachers, 3) goals, 4) selection of contents, 5) teaching and learning methods, and 6) assessment. The *organizational layer* is focused on 1) organization and culture, 2) values and conceptual change, and 3) physical space and resources. This curricular change model is pictured in Figure 2.1.

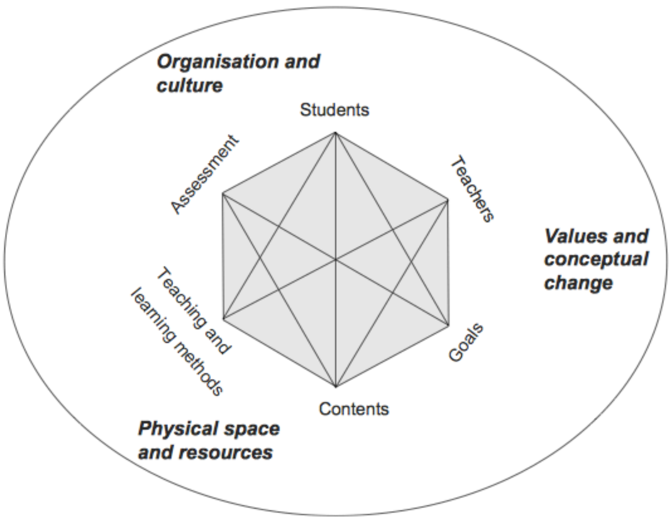

Figure 2.1. Curriculum model for change (de Graaff and Kolmos, 2007)

This model does not define the process for change, but when used in conjunction with Froyd's Organization Change Model, provides a deeper understating of the elements and actors who need their own process of development. The development process and support for the change vision will be strengthened by purposefully addressing each of these in the change process.

2.1.3. CONTRASTING OF PROPOSED MODELS WITH OTHER MODELS FOR CHANGE

Effective utilization of the Organization Change Model and the Curriculum Model for Change require an understanding of what other models could have been used and were not chosen for this work. In the proposal for the Organization Change Model, two other models for engineering curriculum change are identified and evaluated by Froyd, et. al. (2000). The first is described as the "current change model." It is the process used by most faculty members in higher education and is composed of the following steps:

- "Recognize dissatisfaction with an element of their students' performance or participation levels.
- Do an informal search for a solution.
- Choose and implement one or more curricular or pedagogical changes to address the problem.
- Gather informal feedback on the success of the innovation, e.g., observing students' reactions and asking for students' comments.
- Decide whether or not to continue using the innovation, and if a decision is made to continue, decide how to modify the implementation."

Froyd (2000) identifies three reasons this "current change model" will not create the needed widespread transformation:

1. Lack of sufficient rigor required to convince skeptics
2. Motivation arises from individuals' dissatisfaction, and others who don't share the same dissatisfaction and "vision, beliefs, or values" will be unlikely to adopt
3. Faculty members act alone, and research shows sustained change is more likely to happen when innovation occurs through a coalition of committed faculty

Curricular changes from this approach are also often very narrow in scope and generally focus on a single course or set of courses and what a student should "know, understand, and be able to do" (Blackmore & Kandiko, 2012). It doesn't appear that these processes are capable of creating the transformation of engineering education needed to meet the new wave of innovation and technology challenges that graduates will be encountering. The 2013 UNESCO Report on engineering education concurs "there is almost a total lack of action by universities to realize the essential transformation" (Beanland & Hadgraft, 2013). Froyd identifies that if transformation in engineering education is to occur, it is necessary to move past this slow state of incremental change in the U.S. education system toward a model that meets the called for changes. Graham (2012a) also identifies the limited success and meaningful impact of this approach to change.

The second model is the "Espoused Change Model." It has been promoted as a model for facilitating this change and is based mostly upon the scientific method. Froyd (2000) identifies it as the model promoted by many organizations that fund engineering education transformation efforts (including National Science Foundation, NSF) and faculty members themselves. It is based on the following steps:

1. "Conceive curricular change aimed at improvement;
2. Pilot a new curriculum to test the idea;
3. Assess and evaluate results; and
4. Adopt, if supporting results support change" (Froyd et al., 2000)

The underlying assumption is that other engineering faculty will be convinced by the results of these studies and look to implement changes in their courses and curriculums. Again, the evidence shows that this method is not creating the change needed in the engineering education system, especially in the U.S.

Another set of strategies that can be identified for change come from the work of Bennis, Benne, & Chin (1985). They propose three strategy categories for change. They also have shortcomings in creating a model of change, but they are important to identify and recognize, as they are also models commonly used in change processes. They have key aspects that will need to be considered as a new model for an engineering curriculum is developed.

The first category is "empirical-rational strategies." These strategies assume that people are rational individuals who are interested in personal gain; and, if an advantage is pointed out to them, they will make the change to gain this advantage. It is the strategy at the heart of the current change model and the espoused change model described by (Froyd et al., 2000). Empirical-rational strategies are limited in that what is advantageous for the institution may not be beneficial to an individual faculty member. In fact, innovations in engineering education could threaten to diminish the job satisfaction of faculty members who employ already established engineering education methods (de Graaff & Mierson, 2005). This reason is cited by the Royal Academy of Engineering in the 2012 "Achieving Excellence in Engineering Education: The Ingredients of Successful Change" as one of the main barriers to engineering education reform, especially in countries like Germany and the US, where the professor has great control over curriculum. In contrast, countries such as Denmark and Australia are identified for their greater potential to transform engineering education, due to the greater control that administration or campus leadership has over the curriculum (Graham, 2012a). Although these strategies may not produce the desired change in engineering education, the aspect of creating a framework that allows individual faculty members to create rational changes from their own individual perspective in a way that supports the overall desired engineering curriculum transformation of the institution is an important requirement of the change process.

The second category consists of the “normative-re-education strategies,” which assume that people are conservative in nature and places emphasis on the social aspects of human behavior. The main focus is changing the value system of an institution to achieve desired results. The importance of changing the patterns of values and attitudes for the majority of individuals is emphasized as a critical aspect of the change process. This creates a higher acceptability of new ideas that is critical for the success of the Organization Change Model and the institutionalizing of the new curriculum. The challenge of these strategies is the lengthy time they take, which can result in the need for the short-term wins Kotter identifies as necessary for successful change.

“Power-coercive strategies” form the third category, and they assume that a top-down approach is needed because individuals will not recognize the advantages and risks for the entire organization. These strategies are effective in serving the needs of quick visible results for the most urgent of issues, but will have few long-term effects, as the initiative rests with a small group of individuals. Clearly, the long-term nature of engineering education transformation poses a challenge for such strategies. However, they can serve an important part in the initiation of engineering education reform at an institution (de Graaff & Kolmos, 2007) within the initial stages of the Organization Change Model.

Aspects of these other models, with which individuals may be more familiar and/or comfortable using, will need to be addressed as the institution navigates this complex change process and tries to avoid the major dilemma described by Cyert and March in their study of organizations: “The major dilemma in organization theory has been between putting into the theory all the features of organizations we think are relevant and thereby making the theory unmanageable, or pruning the model down to a simple system, thereby making it unrealistic” (Cyert & March, 1959).

2.1.4. CONCLUSION

Change, on the order of developing a new engineering program, is a complex and difficult process. The reality of such a complex level of change cannot be captured by one model. Success requires the use multiple models of understanding change and then using them to guide the process. For this study, the Organizational Change Model will guide the overall process. It will be incorporated with the dual layers and elements from the Curriculum Change Model to provide a deeper understating of the elements and actors in the process of the new PBL curriculum development.

The structural focus of the change is creating common visions that engage all levels of the organization such that the organization creates a genuine, sustained institutional movement. In subsequent sections and chapters, the potential curricular and learning theories for the new engineering curriculum will be developed to define the curricular and organizational elements for the Iron Range Engineering program. This theoretical framework on change will be used in Chapter 3 to analyze the development of the IRE PBL program.

2.2. CURRICULAR THEORY

With the background of change perspectives in place, the next step is to address the curriculum. In this section, curriculum is considered from three viewpoints. First, from a perspective of curriculum in practice, the structural elements are described and arranged in a model. Second, from the literature, a classification framework is presented for use. Third, exemplary practices for the future of engineering curriculum are presented. The outcome of the section is an extensive set of criteria to be used in Chapter 4 to address the objective to *show how the curricular elements of the IRE model are implemented* and to analyze the curriculum from these theoretical perspectives.

2.2.1. CURRICULUM FROM PRACTICE PERSPECTIVE

The curriculum arises to meet the needs of the profession, which includes the profession meeting the needs of society, and the needs of the whole student. The curriculum can then be seen as a compilation or organization of the courses. Crucial to the success of the curriculum is the greater environment in which it is enacted (Barnett & Coate, 2004). Moving down one layer, there is an outline of learning for each course and the environment and enactment of the course. An ultimate goal is to achieve student-learning outcomes that provide them with the tools to meet their own needs and those of their profession, essentially closing the loop from outcomes back to original requirements.

There are many different perspectives that one can assume on curriculum from the perspective of practitioners in higher education. Figure 2.2 shows a model of increasing levels of sophistication. The simplest view would be to consider a program's curriculum as a set of courses. For example, the engineering program curriculum consists of calculus, physics, engineering science, engineering design, etc.

Next would be to consider the courses in combination with objectives for the program. An example of a program objective would be "graduates will be capable of designing, implementing and integrating thermal, electrical, mechanical, and computer-controlled systems and processes that will serve the region, the nation and the world within one to four years of graduation." This is a program objective of the Iron Range Engineering program (ire.mnscu.edu/about-ire/objectives.html, 2016).

Beyond looking at curriculum as a set of courses and objectives, one must consider the design and instruction of the courses as part of the curriculum. Further, one must consider the curriculum from the standpoint of why it exists. For engineering, a viewpoint could be that the curriculum exists to meet the needs of the profession, and in turn, meet the needs of society. For example, Dreher and Kammasch (2014) set a benchmark for engineering education in proposing the Leonardian Oath. Similar to the Hippocratic Oath for medicine, the Leonardian Oath would have curricular outcomes focused on ethical responsibilities such as sustainability and economic impact.

When we graduated with engineering degrees in the 1980's and 1990's, the programs operated under this viewpoint of curriculum. The goal was to complete a set of courses, designed and delivered in a homogenous lecture-laboratory-homework-exam format. Upon graduation, it was expected that we would go and meet the needs of society.

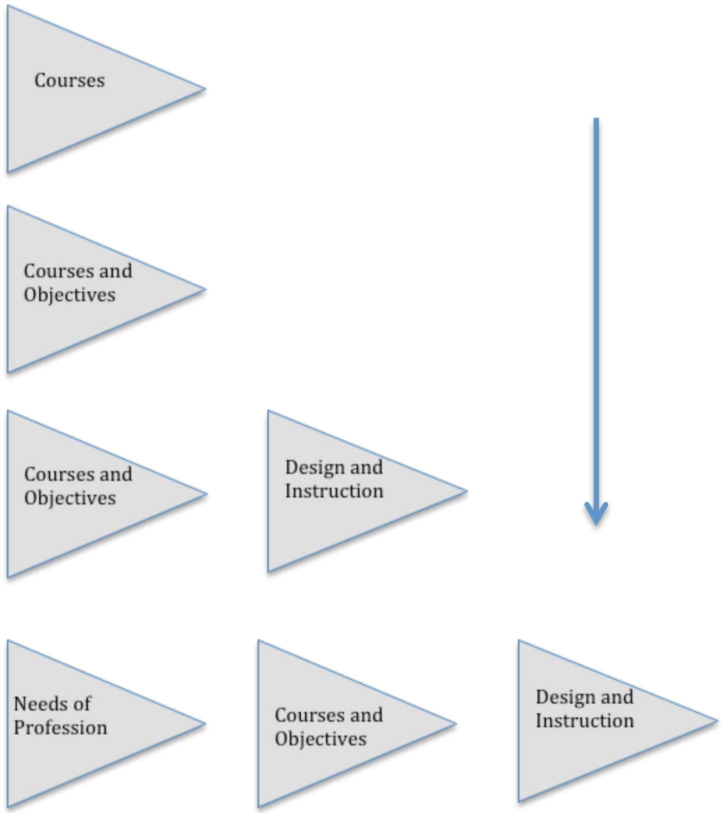

Figure 2.2. Increasingly sophisticated views of curriculum

In the late 1990's, the concept of student outcome in engineering education emerged in the United States (www.abet.org/about-abet/history). In so doing, it added a layer of sophistication. In addition to graduating and being expected to meet objectives to serve society, explicit details were made visible about what skills and competencies the students should have acquired by graduation (ABET a-k). Further, feedback mechanisms within the curriculum became standard. The levels to which students meet the outcomes were assessed and the results fed back to the set of program courses and the design and instruction models. This is the view of engineering program curriculum most commonly held in the U.S. today (ABET 2015). See Figure 2.3.

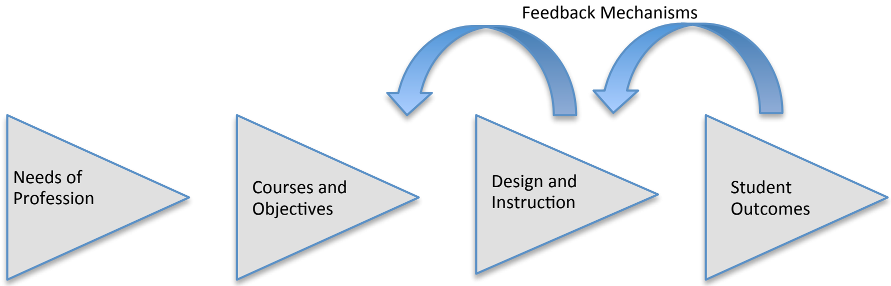

Figure 2.3. Current view of engineering education curriculum in U.S.

Student Outcomes can be identified as both intended student outcomes, those that the curriculum designers would want students to attain, and as actual student outcomes, those that the students actually acquire as a result of their whole experience in the curriculum (Joachim Walther, Kellam, Sochacka, & Radcliffe, 2011).

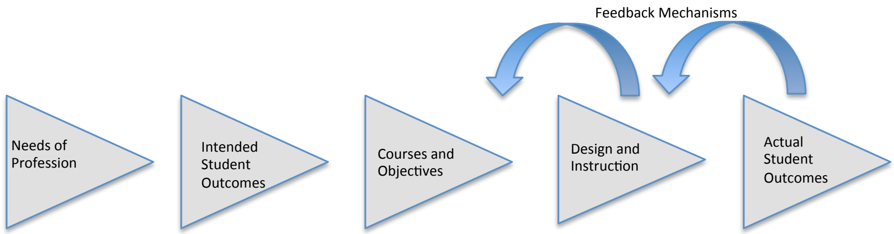

Figure 2.4. Recognizing the difference between intended and actual student outcomes.

Barnett & Coate (2004) proposed that in addition to curriculum being considered as a set of courses and objectives, curriculum is something that is enacted. The delivery of the curriculum in terms of environment and community would play an impactful role in how a curriculum is instituted. To give an example, the Iron Range Engineering program grew out of the Itasca Community College two-year engineering program in Grand Rapids, Minnesota. The list of courses/objectives and model of teaching at this college is very similar to that of other community colleges in Minnesota. However, the student experience of the curriculum is drastically different. The level to which students build identity and achieve success, as impacted by their learning environment and learning communities, is substantially higher (Johnson & Ulseth, 2011).

Beyond Barnett's assertion that curriculum is enacted, as practitioners, we propose that courses are also enacted. As an example, in Spring 2013, the two authors each taught a first-year level physics/statics/engineering design course. We had similar philosophies and followed the same course outlines. Yet, our students' experiences were vastly different. The differences were caused by the different ways in which we enacted the courses, the different stories we told, the different concepts we emphasized, and the different learning activities in which we had our students engage.

Further, just as the curriculum should be designed to meet the needs of the profession and society, it should be designed to meet the needs of the whole student. Figure 2.5 shows a curriculum model that includes meeting the needs of the profession as well as the student, where the program curriculum is a set of courses and objectives that are enacted; where the courses are designed, instructed, and enacted; where there are intended and actual student outcomes; and where there are feedback loops in place for continuous improvement and evolution.

The bordered box identifies the actual student experience. To the left of the student experience are the inputs and to the right is the outcome.

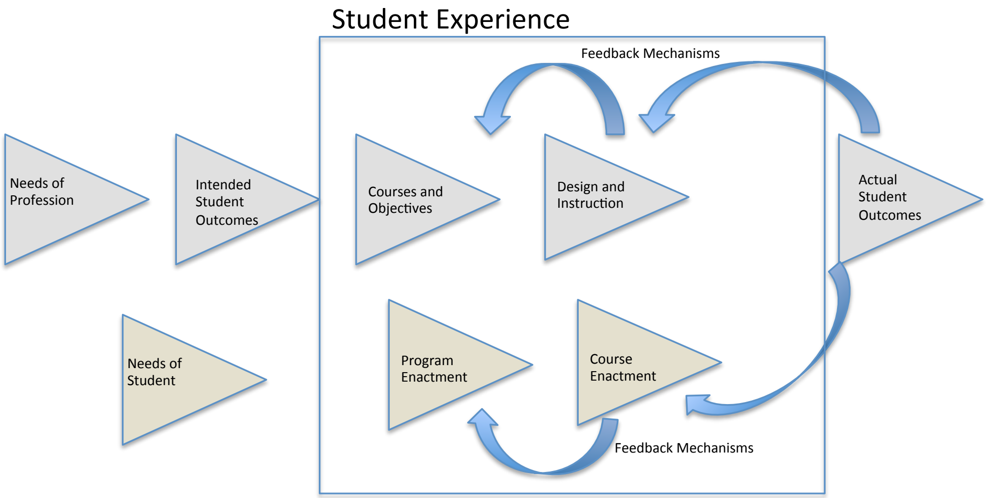

Figure 2.5. Practitioner's view of curriculum

2.2.2. CURRICULUM CLASSIFICATION

There is relevant recent literature regarding the development and implementation of engineering curriculum: Barnett & Coate (2004), Jamison, Kolmos, & Holgaard (2014), Sheppard et al. (2009), Cowan (2006), Rompelman & de Graaff (2006), Kolmos and de Graaff (2014), and Beanland and Hadgraft (2013). Following is an overview of these relevant contributions and connections of these works to one another.

Barnett and Coate (2004) present a classification continuum from knowing to acting to being. Knowing is aligned with the accumulation of knowledge. It brings to mind derivations, theories, information. This classification would be aligned with an emphasis on lecture and developing algorithms to solve closed-ended problems. Jamison et al. (2014) describe this as the ideal of the polytechnic model, or the “scientific university,” where thinking is prized over doing. Most traditional engineering programs fall under this classification.

Acting is the “doing” of engineering. It is learning to engineer by practicing the way engineers will practice in the profession. Cooperative “co-op” experiences or internships in which students are immersed side-by-side with practicing professionals would be an example of this classification. Jamison, Kolmos, and Holgaard classify this model as a market-driven approach or as the “entrepreneurial university.” Here, a wider spectrum of skills and abilities are valued. In addition to technical acumen, abilities to design, communicate, lead, invent, and overall become a practicing professional are the attributes desired in the graduates.

“Being” brings out the humanistic aspects of engineering. It is using the talents of the engineer to solve problems for people, the environment, and society. Activities such as Engineers Without Borders (www.ewb-international.org) and “designing for sustainability” are aligned with being. Jamison, Kolmos, and Holgaard label this as a social and cultural orientation and term the programs as being from the “ecological university.” The individual brings civic engagement and responsibility to the community as higher-level values to their practice.

While the Barnett and Coate classifications of knowing, acting, and being are presented above as discreet, they are more of a continuum. In-place curricula around the world differ in the various emphases put in each of these areas. In any space where one of the values is placed above the other two, such as KNOWING-acting-being; knowing-ACTING-being; or knowing-acting-BEING; the curricula could be so classified, and then flavored by the other two. Beyond knowing-acting-being, Jamison, Kolmos, and Holgaard propose a model of Hybrid Imagining, a place where all three areas are equally valued. This would be a concept of KNOWING-ACTING-BEING. They imagine a future in which this model could be the ultimate goal of curricular design in engineering education.

These conceptualizations arise in the perceived needs of the profession/society. Curriculum designers have to interpret these needs and their place along the continuum. These interpretations, along with any externally imposed mandates, such as by accrediting agencies, then lead to the development of the intended student learning outcomes. The actual student-acquired outcomes will be the results of how the courses are designed, how the instruction is designed, how the courses and instruction are enacted, and the level to which feedback is used in the processes to influence continuous improvement. In some cases, there will be close alignment along the knowing-acting-being continuum of what was intended and what the graduates acquire. Sometimes, there will be poor alignment. For example, ABET requires that its accredited institutions have a fixed set of intended student learning outcomes, the ABET a-k. These outcomes could be classified as KNOWING-ACTING-being. Five of the outcomes are more technical, six of the outcomes are more professional, and only a few are tangentially societal. Thus, graduates of ABET-accredited engineering programs should have nearly equally high levels of technical and professional competence. However, course and instruction design and enactment lean much further toward the technical development (Sheppard et al., 2009). Graduates acquire KNOWING-acting-being attributes. This misalignment is an example of a major source of the calls for reform that were summarized in Section 1.3.

In the coming presentation of future models of curriculum, we will classify using the knowing-acting-being from Barnett and Coates and the polytechnic, entrepreneurial, ecological, hybrid imagining from Jamison, Kolmos, and Holgaard.

2.2.3. EMERGING MODELS OF CURRICULA

Spiral-Networked Model

Sheppard et al. (2009) present a "spiral-networked" curriculum model aimed at preparing graduates to be life-long learners. The spiral visually represents a circle of learning wherein fundamental principles of engineering are introduced on the first revolution, then used at higher and higher levels of sophistication on subsequent revolutions (see Figure 2.6).

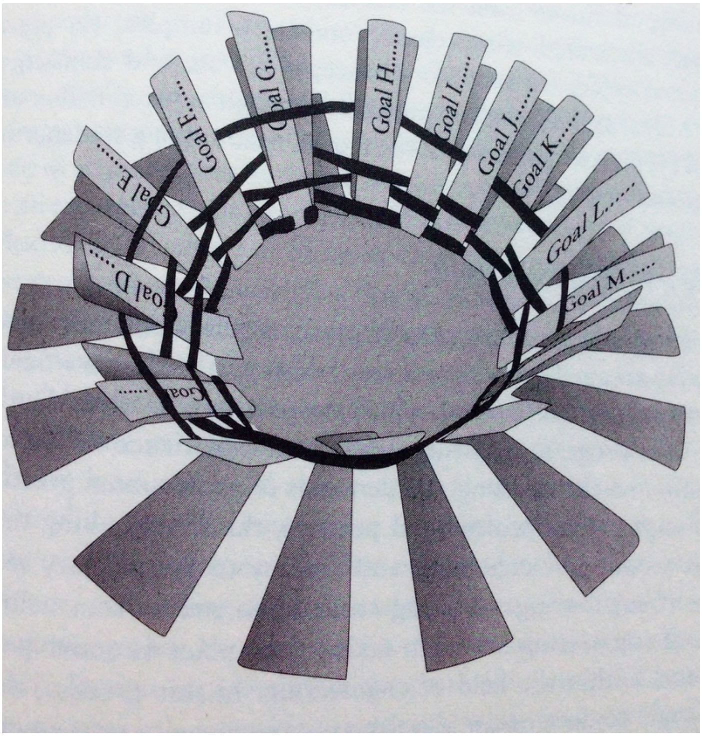

Figure 2.6. Sheppard networked component model (used with permission)

They propose that the learning is situated in activities that closely simulate those activities engineers undergo in professional practice. These activities develop the technical knowledge while developing the professional skills necessary for successful daily interactions in engineering practice. They also develop abilities that use the technical knowledge and professional skills to solve the complex engineering problems faced by engineers. Additionally, engineering students, as they traverse the spiral, would develop the identity and attitudes that allow them to react dynamically to change and persist toward solutions.

The visual model of the spiral is further described to include movement back and forth between specific situations and basic engineering principles, giving students practice in grounding their new work in fundamental science. Continually increasing sophistication in subsequent revolutions would provide students with the ability move along the trajectory toward engineering practice.

These goals proposed by Sheppard are what the engineering student would look like at graduation and thus are the proposed actual student outcomes. The attributes of the spiral-networked model include: 1) a focus on professional competency development, 2) a focus on the use of fundamental principles and their interconnectivity, 3) environments similar to engineering practice, and 4) immersing students in the physical world and empowering them to make connections, doing so multiple times throughout their education.

The spiral-networked model would be classified as KNOWING-ACTING-Being with some attention given to building engineering identity, but little emphasis on the humanistic value of the profession. Jamison, Kolmos, and Holgaard would classify this model as having attributes of both the polytechnic and entrepreneurial university. The spiral-networked model fits with the practitioners' view of curriculum from Figure 2.5 in the ways that it addresses the needs of the profession, the intended outcomes of the graduate, and both the design and enactment of the courses.

The value of the spiral-networked model is in classifying the level of professional skill focus, emphasis on fundamental principles, immersion in real engineering environments, and degree of use of a spiral model in engineering curricula.

Systems Engineering

Rompelman & de Graaff (2006) apply a systems engineering approach to viewing a curriculum. They identify the system boundaries as encompassing the students, the teachers, and the interactions between students and teachers. Within this boundary, then, is the educational process. The inputs to the system are the educational objectives. The output is the student, including his/her attributes. Assessment is a key that empowers several feedback loops. Assessment of the abilities of the student output provides feedback to the input (objectives), feedback to the students in the system, and feedback to the teachers in the system. Summative assessment is also an output of the results of the system.

Rompelman and de Graaff follow their view of curriculum by taking an engineering designer's approach to building a curriculum. They define the need for a new curriculum as a problem to be solved, identifying a problem as a gap between what is and what is desired. Using standard design principles, they look at problem definition and criteria definition. This leads to a product requirements plan, development of solutions, simulation and evaluation of solutions, and selection of the best solution. Transferring the design approach of a product to the design of a curriculum, analogies are made. Desired outcomes become the problem definition. The product requirements plan becomes the course requirements plan. Solutions come in the form of choosing appropriate learning activities that are likely to align with desired outcomes. Evaluation is made to compare the viability of the different solutions options against the course requirements. Then, a final selection is made based on the evaluation.

The practitioner's view of curriculum shown above in Figure 2.6 is similar to the systems engineering model. Slight dissimilarities exist, in that the practitioner's view further breaks down the objectives into needs of the profession and needs of the student, and further defines the educational process to include the program and course design, program and course instruction, and program and course enactment.

This design-based approach of the systems engineering model highlights the need to address alignment of outcomes and instructional approaches. It will be used to classify curricular models based on the inclusion of a method to continuously monitor, through feedback mechanisms, the alignment of instructional methods with desired outcomes.

Project-Based Learning

Kolmos et al. (2014) present PBL as a curriculum. They define three separate, yet interrelated PBL learning principles: learning, social, and contents. Learning includes problem solving, ownership of problems, and organization of learning. Social is team-based with interaction between the individual and her or his group. Learning takes place through conversation. Students share knowledge and collaboratively construct it. Contents are the interdisciplinary fundamental principles of engineering, learned through an approach similar to that of a scientist conducting research or through other exemplary methods.

Through the PBL learning principles, alignment theory, and social construction theory, they identify 7 curricular elements to PBL: 1) outcomes, 2) types of problems and projects, 3) progression, size, and duration, 4) students' learning, 5) academic staff facilitation, 6) physical space and organization, 7) assessment and evaluation. From these elements, we have further methods for classifying curricula. Are problems or projects used and to what extent (courses or whole curriculums)? Is the student learning receptive or constructive? What level of facilitation training does academic staff receive? How is physical space allotted for learning? What levels of individual/group and formative/summative assessment are used?

PBL includes all of the aspects in practitioner's view of curriculum in Figure 2.6. There are intended student outcomes, aligned with instruction, aligned with actual outcomes. PBL is dependent on enactment at the course and program (curriculum) levels. Further, PBL has assessment and evaluation feedback loops to all aspects of the curriculum. Kolmos and de Graaff describe the motivations for PBL and show them as the needs of the profession for new engineering competencies. The social requirements of PBL align with our view of the needs of the student. In summary, the principles of PBL and its phases of implementation align very well with our complete view of curricula. However, it is how institutions and individual faculty members enact PBL that will determine what kinds, and to what extent, actual needs are met.

The description of PBL as a curriculum can be connected to the previously discussed models and views. For Barnett and Coates, different institutions could enact PBL differently, to put emphasis on any of the different knowing-acting-being models. From Jamison, Kolmos, and Holgaard, the same could be said; depending on institutional enactment, emphasis could be on scientific, entrepreneurial, ecological, or hybrid imagining. However, by its nature, PBL leans toward engineering practice as seen in entrepreneurial, ecological, and hybrid imagining. From Sheppard, PBL curricula can be enacted in a spiral model, with a professional spine, with a focus on fundamental principles, and in an immersion in professional practice. By its nature, PBL integrates knowledge and skills in an approximation of engineering practice. From Rompleman and de Graaff, PBL is a curriculum that, by design, has alignment between outcomes and instruction. Similarly, PBL has feedback mechanisms to monitor the alignment.

2.2.4. ESSENTIAL CURRICULAR ATTRIBUTES

In addition to the models of curriculum presented above, two essential attributes to consider are reflection and identity building. In the upcoming section on learning theory, the important elements in the design of learning environments are described and synthesized. Reflection and identity are included in that discussion but, due to their critical importance, are first included in this discussion on the design of curricula.

Reflection

Reflection “is a vital and rigorous component of the learning process and a critically important part of the engineering profession” (Lima & Oakes, 2014). Cowan (2006) brings a new perspective to the aspects of curriculum previously discussed. This perspective is that of reflection in the learning process. Cowan presents three learning principles related to reflection and then presents a model for reflection.

Cowan’s principles: 1) developing the ability to do something comes from examples, 2) people who think about “how” they do something will improve at doing it, 3) people who think about “how well” they do things and how well they “could do things,” are more effective self-directed/managed learners.

These principles lead directly to Cowan’s three-part model in which a learner reflects before learning, during learning, and after learning. Before learning is termed “reflection-for-action.” The learner connects prior learning to what is about to be learned. The learner then plans for the learning to come by setting goals, organizing resources, and purposefully determining the rate and effort to be expended on the learning. During the learning, the second reflection, "reflection-in-action," takes place. At this point, the learner recaps what is being learned and how it is being learned. The learner takes this time to ensure alignment between the goals and the learning activity as well as predicting the likelihood of success of the learning. Lastly, is reflection-on-action where the learner identifies the value of the learning, evaluates the quality of the learning, and describes how the learning will carry forward.

Cowan's reflection model fits in the area of course enactment. The importance of reflection is embodied in the metacognitive aspects of learning. It happens at the content level in engineering education and at the intersection of the instructor and the student. Undergraduate students tend not to have developed this level of sophistication in their ability to become self-directed learners. Instructors need to convince students of the value of reflecting, model reflection for the students, and give them formative feedback on their reflective abilities. Left on their own, instructors will implement reflective practices with their students on a continuum of "not at all" to "quite well." Therefore, if the development of reflective abilities is to be an actual outcome at graduation, it should be stated as an intended outcome in the development of the curriculum. Additionally, instructors should be given proper training in how to develop reflective abilities in their students. This would be evident in the program enactment of our view of curriculum.

To classify Cowan's view of reflection among the previously discussed curricular aspects, reflection in the development of self-directed learning would be of high value in any of Barnett and Coate's knowing-acting-being or Jamison, Kolmos, and Holgaard's scientific-entrepreneurial-ecological-hybrid imaging classifications. Though, reflective practice could be more highly valued in the "being" and "ecological or hybrid imagining" models. The act of reflecting to connect prior learning to current learning, and connecting current learning to future learning, is evident in Sheppard et al.'s spiral model where learning goals are made explicit to students and monitored for alignment. Similarly with Rompleman and de Graaff's model, reflection is key to feedback mechanisms ensuring alignment of learning outcomes with instruction. Kolmos and de Graaff's model of PBL has, as a key component, both individual and team reflection. For further classification purposes, we will identify to what degree curricula include reflection as a priority for student learning and outcomes.

Identity

Dehing (2013) identifies the importance of identity building as a component of engineering curricula. They point out that the value of professional identity building is to increase motivation for student learning and make the connection that students with higher professional identity develop higher learner maturity, becoming more self-directed learners. They define professional identity as having two dimensions.

There is a social dimension in which the individual “acts” like an engineer by meeting the requirements of the profession. There is also an individual dimension in which the person feels like an engineer, as displayed through their definition of themselves regarding beliefs, values, attributes, and motives.

Dehing, et al., further describe the attributes of a curriculum that lead to the development of professional identity in engineering students: 1) have identity development as an explicit goal of the curriculum, 2) treat students as “student engineers” from the beginning of their education, 3) align the curriculum with the professional practice of engineering, 4) provide a presence of practice professionals for mentorship, 5) ensure that teaching faculty have a shared and explicit view of professional behavior.

To align identity with the practitioner’s model of curriculum: place identity building as an intended student outcome, consider the alignment of professional practice and presence of practicing professionals a part of the curricular design, and place having teaching faculty develop shared/explicit view of professional behavior in program enactment and course enactment. Professional identity building aligns with Barnett and Coate’s as knowing-ACTING-being and with Jamison, Kolmos, and Holgaard in the entrepreneurial university and in their hybrid imagining. Professional identity building is central to Sheppard et al.’s spiral model of developing the future engineering professional. Kolmos and de Graaff’s PBL model lends to the development of professional identity through the action of students practicing engineering throughout the entire curriculum and the use of physical space to provide a place for engineering practice.

2.2.5. CURRICULAR TRANSFORMATION

Beanland and Hadgraft (2013) utilized 15 contributing panels to publish the UNESCO Report, Engineering Education: Transformation and Innovation. They first made a case for transforming engineering education, then provided a model for transformation, finishing with a look at how to make transformation happen. This model for transformation serves to tie together much of the works discussed above.

Beanland and Hadgraft identify that transformation should occur in regards to curriculum structure and content (design) as well as in program delivery (enactment) and assessment (feedback). They produce 6 key steps to guide the design and implementation of engineering curricula: 1) adopt Washington Accord attributes (actual outcomes), 2) maximize development of capabilities essential to engineering practice (actual outcomes), 3) first-year experiences designed and enacted to maximize student motivation (design and enactment), 4) use PBL in each year (design), 5) replace lecture with student learning (enactment), 6) use wide range of IT and communication systems to facilitate student learning (enactment).

Further, the report makes the following arguments (where appropriate, relevancy from the works listed above is shown in parentheses):

- "It is suggested that engineering students should be treated as trainee engineers and confront engineering issues from day one of their program" (spiral network, identity building)
- "… engineering projects are the vehicle to:
    - introduce breadth of engineering understanding in early years
    - develop motivation and commitment to engineering
    - develop communication skills
    - introduce ethical and social responsibility and business dimensions of engineering
    - address the sustainability of engineering projects
    - require innovation in the realization of solutions
    - develop specialized knowledge in capstone projects."

  (PBL, spiral network, identity building)

- "It is not desirable nor effective to build the program around a series of ineffective, and consequently inefficient, lecture presentations when the alternative exists to use a project-based program to create student-centered learning which is consistent with the development of the desired engineering graduate attributes. This is the core issue. It is the key to transformation. It requires major change." (PBL, spiral network, identity building, systems engineering)
- "To seriously promote student-centered learning a dedicated home-room, which provides an engineering project office-like environment, is required." (PBL)
- "Students and academic staff work together to monitor and record the progress toward achieving specified learning outcomes to optimize the effectiveness of student learning…" (reflection, systems engineering)

The report concludes with 24 elements that are key to the transformation. The following are highly relevant to this discussion on curriculum listed with the germane discussion models from above:

4) Curricula should be implemented using project-based pedagogies (PBL)

7) Curricula should be focused on providing personal learning experiences aimed at developing engineering practitioners (spiral-networked, PBL)

9) Outcomes should include the development of attributes essential for the practice of engineering (engineering systems, PBL, identity)

13) Teaching faculty should facilitate personalized student learning through the use of student-centered learning activities (PBL)

17) Physical learning spaces need to be altered to accommodate project-based and student-centered learning (PBL)

23) Engineering employers should form effective partnerships with learning institutions to empower the transformation (identity)

In summary, the UNESCO report calls for transformation in engineering education and does so by proposing many of the curricular components that are addressed in this section.

2.2.6. FRAMEWORK FOR CLASSIFYING

The synthesis of the curricular components provided above results in a framework for analyzing an engineering curriculum. The framework is presented below as series of questions. The answers to the questions classify according to its attributes in regards to its intent, design, and enactment.

Curriculum Classification

Is there a higher emphasis on knowing, acting, or being? Or are they valued equally?
Is the program scientific, entrepreneurial, or ecological? Or hybrid imagining?

What are the intended student learning outcomes?

To what level do they align with the Washington Accord?
To what level is instruction aligned with outcomes?
To what level is enactment aligned with outcomes?
Is identity building an intended learning outcome?

Are intended learning outcomes realized as actual student outcomes?

Is there a continuous feedback system to ensure alignment of intended outcomes, instructional design, program enactment, and course enactment with actual student outcomes?
To what level is the alignment achieved?

Are the needs of the student addressed in the curriculum design and enactment?

To what level is motivation for student learning considered in the design and enactment of the curriculum?
To what levels are students included in the decision making of learning activities?

To what levels do faculty involve students in analyzing their progress in achievement of their learning outcomes?

Does the curriculum design/enactment align with exemplary practice?

To what level does the curriculum align with professional practice?
Is PBL used? To what level?
To what level does the curriculum have and enact a professional spine?
Where does learning fall on the continuum of lecture/receiving to student-centered/active/constructive?
How is physical space allotted for student-centered learning?
How is assessment conducted?
(Formative/Summative?, Individual/Group?)
To what level are students treated as student engineers?
To what level do teaching faculty share and explicate a common view of professional practice?
To what level are students exposed to practicing professionals?
Does academic staff receive training in facilitation?
To what level is reflection used in student learning?
Are students given feedback on their reflective abilities?
Are academic staff trained in giving feedback on reflection?
How are fundamental principles interconnected with each other and engineering practice?
Is a spiral model implemented for the learning of fundamental principles?

Figure 2.7. Framework for classifying engineering curricula

The UNESCO report states "…curriculum is a multi-variable complex engineering problem. It does not have a unique solution, but it does have some essential elements…" Multiple perspectives of engineering curricula have been presented and related to one another in order to develop the above classification framework. The framework, when applied to an existing or new curriculum, can paint the picture of that unique curriculum. The framework consists of over 25 questions. Most of the questions have answers that are on a continuum from low to high. In Chapter 4, this framework for classifying curricula is used to classify the Iron Range Engineering curriculum to further address the objective to *show how the curricular elements of the IRE model are implemented.*

2.2.7. CONCLUSION

In summary, we have presented curriculum theory from a variety of perspectives. First we developed a look of curriculum from the point of view of engineering education practitioners. Next, we discussed curriculum classifications. Third, we analyzed emerging curricular models. Finally, we detailed two essential curricular elements. All of these perspectives were synthesized into a framework for classifying curricula. The framework is a set of many questions, the answers to which create a unique "fingerprint" of that curriculum, enabling it to be described and compared to others.

<u>Key Finding:</u> This framework will be applied to analyze the Iron Range Engineering model in Chapter 4. It also creates a taxonomy for classifying any PBL curriculum. As PBL is implemented more widely, it provides a "common language" for comparative discussion in understanding what individuals involved with curricular change aspire to accomplish with a PBL curriculum.

2.3. LEARNING THEORY

The curricular theory discussion in the previous section covers a broad set of aspects. This section on learning theory focuses on one of the most critical of those aspects. To give an analogy, if curriculum were compared to a person's house, including their front yard and back yard, learning, then, would be an important room in the house such as the kitchen or the family room. PBL is a learner-centered pedagogy. Our motivations to start the IRE program and undertake the PhD studies are learner-centered. Thus, learning theory has become an important focus of study and is essential to address the objective of *analyzing the Iron Range Engineering program through theory.*

Following is a development of learning theory and design of learning environments using relevant literature. Illeris (2007) presents a framework for learning that serves as a model through which learning theories and aspects of a learning environment can be viewed in regard to their contribution to the learning process. We start by describing Illeris' model (2007) and then use Bransford et al. (2006) and Bransford, Brown, & Cocking (2000) to give validation to Illeris' model. Next, we present a discussion on constructivism as the primary theory of learning on which modern views of best practice are built, and include the American Psychological Association's learner-centered psychological principles while placing these in Illeris' model. This is followed with a literature-based description of the following relevant elements of learning and learning environments: development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity. We will describe each, discuss their relevance, and position them in the models of Illeris and their connection to the APA principles. Finally, we present a synthesis of this work to build a framework from which we will be able to apply to the Iron Range Engineering model analysis in Chapter 4.

2.3.1. ILLERIS MODEL OF LEARNING

Knud Illeris developed a forward-looking model of learning that allows a conceptualization of the different tensions that impact learning. His motivation was to develop a concept of learning that accounts for the complex acquisition of the wide range of competencies that encompass traditional knowledge and analytical skills, overview capability, life skills, professional responsibility, and attributes such as flexibility, dynamism, creativity, leadership, and more (Illeris, 2003). He goes on to state that for any learning to take place, there must be two basic processes in play: internal interactions involving the psychological process of acquisition and elaboration, and external processes of interaction between the learner and his or her social, cultural, and physical environments.

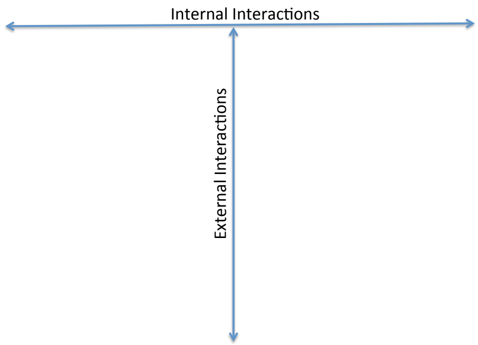

Figure 2.8. Two processes of learning (adapted from Illeris, 2007)

Illeris (2007) identifies three dimensions of learning. These are content, incentive, and interaction. The content dimension refers to the competencies of knowledge, skills, and understanding. It is in this dimension that learning is acquired. It is the development of cognitive ability. The second dimension is incentive, wherein the motivations for learning are considered. In a simplistic view, if we consider the content dimension to be *what* is learned, the incentive dimension would be *why* the learner wants to learn and takes into account the emotions of learning. The third dimension considers the interactions that take place during the learning: the interactions between the learner and her learning community, and those between the learner and her environment. This is the social aspect of learning and could be considered part of the *where* and *how* the learning takes place. Illeris places these three dimensions of learning at their appropriate points on the ends of the process lines. See Figure 2.9 below.

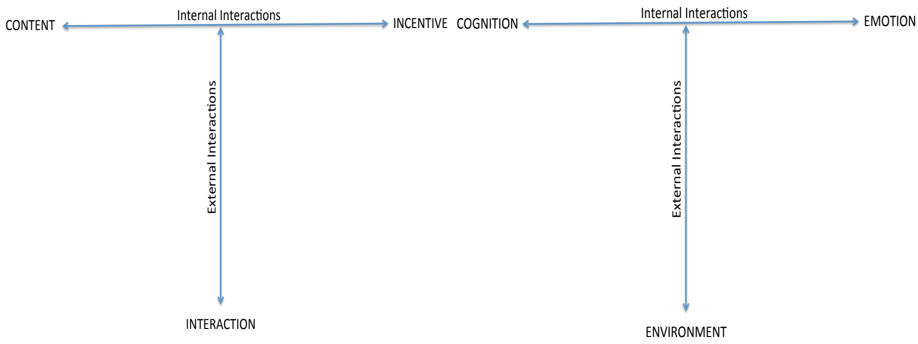

Figure 2.9. Illeris dimensions of learning

The content dimension is annotated by cognition, meaning, and functionality. Incentive is further described by emotion, sensitivity, and mental balance. At the top edge of the triangle, the leg between content and incentive is about the individual acquiring knowledge. When moving down toward sociality, the interactions between the student and the environment are considered.

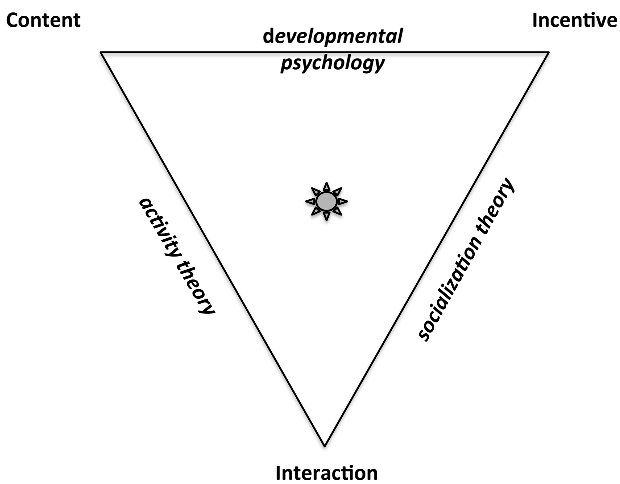

Figure 2.10. Illeris triangle (2002)

Illeris' theory is that learning takes place at the intersection of content, incentive, and interaction, or near the centroid of the triangle. Also, in Figure 2.10 Illeris labels the legs of the triangle with the relevant theories of learning where developmental psychology lies between the cognition and emotion vertices, socialization theory between emotion and society, and activity theory between cognition and society.

Beyond the three dimensions of learning, Illeris describes four types of learning: cumulative, assimilative, accommodative, and transformative. Cumulative learning takes place when the learner is entering the domain for the first time and has no previous mental frameworks on which to build the new learning. Assimilative learning takes place when previous learning has occurred when there are mental structures on which to build as new information is received through sensory input. Accommodative learning takes place through mental processes such as reflection, where the learner restructures mental models from one conception to another. Transformative learning can be viewed as a "complex accommodation involving the simultaneous restructuring of several cognitive as well as emotional schemes" (Illeris, 2003). He further indicates that transformative learning takes place in times of crisis when the individual is confronted with the need to quickly overcome a situation that exceeds her previous knowledge structures.

In the Cambridge Handbook of The Learning Sciences, Bransford et al. (2006) present three recent major insights on the understanding of learning and thinking:

1) The extent to which local cognition and social ecology can support or constrain learning.
2) Importance of social aspects of learning as people engage with learning activities, one another, and their identities as learners and doers of particular activities.
3) Role of cultural practices for learning and the understanding that arrangements and values for learning are themselves cultural practices.

These three insights support the placement of learning in the center of Illeris' triangle where cognition is balanced by self and interaction of self with the activity and the social and cultural environments.

Sawyer (2005) further verifies the ideals present in Illeris' triangle. In his introductory chapter to the Cambridge Handbook of The Learning Sciences, justifying that learning science reform is based on professional practice, he states that "knowledge is not just a mental picture inside the learner's head; instead, knowing is a process that involves the person, the tools, other people in the environment, and the activities to which that knowledge is applied."

In summary, Illeris has developed a model for conceptualizing learning. We have described the model and provided evidence that the works of modern day leaders in learning science, Bransford and Sawyer, validate Illeris' model. Illeris identifies his model as being constructivist (2003). Following is an overview of constructivism.

2.3.2. CONSTRUCTIVISM

Rooted in the works of Jean Piaget and Lev Vygotsky from the early 1900's, the premise of constructivism is that rather than knowledge being acquired from others, each individual constructs much of what they learn (Schunk, 2009). Further, the learner's own experiences are integrated into what is learned (Jarvis, Holford, & Griffin, 2003). In contrast to instructionism, where the teacher is seen as the expert who delivers knowledge in one direction to the learner, in constructivism the teacher works from around the edges to empower the learner to build the knowledge for herself (Schunk, 2009).

There are three paradigms of constructivism: exogenous, endogenous, and dialectical. In exogenous constructivism, learning happens as the learner interprets his environment. Endogenous constructivism is a re-working of knowledge structures from within the learner's own mind. Dialectical constructivism is the construction of new mental frameworks that takes place at the intersection and interaction between the environment and the individual (Moshman, 1982).

Vygotsky (1978) presented a model for understanding the relationship between the learner and more capable guide to learning, whether teacher or peer. The distance between the level of the learner and the guide is termed the Zone of Proximal Development, and it is in this zone that cognitive change can happen. Tharp and Gallimore (1988) described stages in the ZPD to include being assisted by more capable others, constructing one's new knowledge, restructuring through internalization leading to automatization, and deautomatization, which can result in loss of the automated knowledge/skills through loss of practice or time since use, which would necessitate revisiting the ZPD.

Connections can be made to Illeris' four types of learning as stage 1 would be the beginning of cumulative learning. Assimilative learning takes place through stage 1 and into stage 2. Accumulative learning follows through stage 2 and into stage 3. The ZPD model doesn't explicitly address Illeris' transformative learning.

In The Process of Education, Bruner (1977) identified his constructivist-based principles of learning. The first principle addressed readiness of the learner to learn. The second principle brought forth the spiral model of learning that Sheppard et al. (2009) revisited in Educating Engineers. Here the fundamental principles are revisited at increasing levels until mastery is achieved. Bruner's third principle stated that the learner should have to actively fill in the gaps, that learning should go beyond the presented information, thus the learner must actively construct knowledge. Social constructivism goes beyond the individual constructing her own knowledge, to the public space where meanings are socially negotiated (Bruner, 1990). In other words, constructed knowledge is a part of, not distinct from, the social and cultural fabrics within which it is created.

To place these understandings of knowledge construction in Illeris' triangle, we have constructed content from the upper left vertices, readiness for learning from the upper right vertices, and interaction with peers, teachers, culture and society, from the lower vertices. We have placed constructivism/social constructivism in the middle of the triangle. Illeris places Bruner and Vygotsky works along the left leg of the triangle, between the stronger influences of content and interaction, with less from the incentive.

2.3.3. APA PRINCIPLES

Reflecting a social constructivist approach (Schunk, 2009), in 1997, the American Psychological Association (APA) developed learner-centered psychological principles to provide a forward-looking framework for education reform (APA, 1997). These 14 principles are divided into four categories: cognitive/metacognitive, motivational/affective, development/social, and individual differences. The first 11 principles, when taken individually, can be placed on Illeris' tension triangle. They demonstrate importance at all three vertices and in the center. Figure 2.11 shows the APA principles.

Cognitive and Metacognitive Factors

1. Nature of the learning process – The learning of complex subject matter is most effective when it is an intentional process of constructing meaning from information and experience.
2. Goals of the learning process – The successful learner, over time and with support and instructional guidance, can create meaningful, coherent representations of knowledge.
3. Construction of knowledge – The successful learner can link new information with existing knowledge in meaningful ways.
4. Strategic thinking – The successful learner can create and use a repertoire of thinking and reasoning strategies to achieve complex learning goals.
5. Thinking about thinking – Higher order strategies for selecting and monitoring mental operations facilitate creative and critical thinking.
6. Context of learning – Learning is influenced by environmental factors, including culture, technology, and instructional practices.

Motivational and Affective Factors

7. Motivational and emotional influences on learning – What and how much is learned is influenced by the motivation. Motivation to learn, in turn, is influenced by the individual's emotional states, beliefs, interests and goals, and habits of thinking.
8. Intrinsic motivation to learn – The learner's creativity, higher-order thinking, and natural curiosity all contribute to motivation to learn. Intrinsic motivation is stimulated by tasks of optimal novelty and difficulty, relevant to personal interests, and providing for personal choice and control.
9. Effects of motivation on effort – Acquisition of complex knowledge and skills requires extended learner effort and guided practice. Without learners' motivation to learn, the willingness to exert this effort is unlikely without coercion.

Developmental and Social Factors

10. Developmental influences on learning – As individuals develop, there are different opportunities and constraints for learning. Learning is most effective when differential development within and across physical, intellectual, emotional, and social domains is taken into account.
11. Social influences on learning – Learning is influenced by social interactions, interpersonal relations, and communication with others.

Individual Differences Factors

12. Individual differences in learning – Learners have different strategies, approaches, and capabilities for learning that are a function of prior experience and heredity.
13. Learning and diversity – Learning is most effective when differences in learners' linguistic, cultural, and social backgrounds are taken into account.
14. Standards and assessment – Setting appropriately high and challenging standards and assessing the learner as well as the learning progress -- including diagnostic, process, and outcome assessment -- are integral parts of the learning process.

Figure 2.11. American Psychological Association learner-centered psychological principles (APA, 1997)

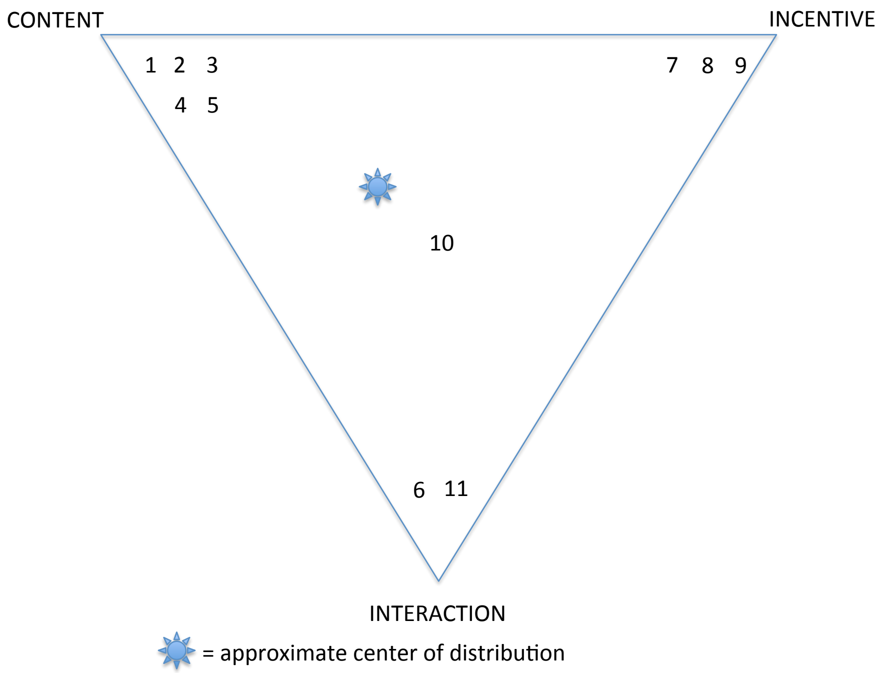

Figure 2.12. Distribution of APA principles on Illeris triangle

The APA took a stand saying the evidence (at the time) on learning pointed toward models that follow these principles. The principles are, for the most part, social constructivist in nature. Viewing these principles through the lens of Illeris' tension triangle shows the principles being valued in all three dimensions. Figure 2.12 shows the APA principles super-imposed on Illeris' triangle. A geographical center of the principle would be shaded to the upper left of the triangle's centroid. From our perspective, nearly 20 years after the APA principles were published, there is an imbalance in this distribution. It appears as though the APA principles, at least in quantity, did not give appropriate value to the social and environmental impacts on learning.

This criticism aside, we see value in using the APA principles, taken individually, as a way to view the learning attributes of the elements in a learning environment. In future sections and chapters, the Illeris triangle and the APA principles are used to ground aspects of learning in general and the IRE model in specific.

2.3.4. ELEMENTS OF LEARNING AND LEARNING ENVIRONMENTS

We now present literature-based descriptions of the following relevant additional components for designing of learning and learning environments: development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity. We will describe each, discuss their relevance, and position them in the models of Illeris and their connection to the APA principle

Kafai (2006) distinguishes between constructivism, which is a theory of knowledge development, and constructionism, which is a theory of teaching and learning that is based on constructivism. As this Learning Theory section of Chapter 2 develops, we move from a view of what learning is, toward the frontiers of how learning happens. As the world evolves technologically and becomes more complex, instructionism continues to fail to meet the educational needs of learners (Sawyer, 2005). In the past 20 years, emerging from the theory of constructivism, social constructivism, and the concept of constructionism is a new science of learning.

Bransford et al. (2000) imply that learning should consist of deeper conceptual understanding, focus on the learner in addition to the teacher, use prior knowledge to build new, focus on the learning environment, and focus on reflection. Their work is closely paralleled by the afore-mentioned principles published by APA. The concepts that make up this new science of learning are the foundations for the development of learning systems: development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity.

These elements range from attributes specifically focused on the learner to attributes of the structures around the learner. Following are the theoretical underpinnings of these concepts, followed by a placement of the components in Illeris' model of learning.

<u>Developing Expertise</u>

Experts are differentiated from novices in that they have the ability to efficiently encode domain specific details to quickly process and adapt to unique situations. They have substantially large sets of complex long-term memory structures and procedures (Sawyer, 2005; Schunk, 2009). In addition to having more knowledge, experts have that knowledge identified in a manner called conditionalizing, so that they may identify its relevance or irrelevance to any particular situation. Experts tend to organize their knowledge around the fundamental principles of the domain while novices tend to rely on memorizing procedures (Bransford et al., 2000). As a result of these abilities of experts, they can recognize features in problems that novices do not notice. Another attribute distinguishing experts from novices is their proficiency at reflecting on their thinking during the thinking processes (Sawyer, 2005).

Bransford et al. (2006) developed a model for adaptive expertise that differentiates between routine experts and adaptive experts. The difference is in the ability to innovate. They put forth that most educational environments are designed for routine expertise and purport that learning environments, to develop adaptive expertise should heavily emphasize reflection and metacognition, involve inquiry focused on confirming/disconfirming theories rather than following standard procedures, and involve students in inventing and developing instruments to work more efficiently.

A connection of developing expertise to the Illeris model of learning would place it in the upper left section of content as this work on expertise is focused on cognition with little connection to incentive or interaction.

Reflection

As indicated in Section 2.2, reflection is highly valued in the design and implementation of the IRE model. We considered it an essential element in the curriculum and here, again, as an element in the design of a learning environment. In his landmark texts, The Reflective Practitioner and Educating the Reflective Practitioner, Donald Schön presents the perspective that:

> *"In the varied topography of professional practice, there is a high, hard ground overlooking a swamp. On the high ground, manageable problems lend themselves to a solution through application of research-based theory and technique. In the swampy lowland, messy confusing problems defy technical solution. The irony of this situation is that the problems of high ground tend to be relatively unimportant to individuals or society at large, however great their technical interest may be, while in the swamp lie the problems of greatest human concern. The practitioner must choose. Shall he remain on the high ground where he can solve relatively unimportant problems according to prevailing standards of rigor, or shall he descend to the swamp of important problems and nonrigorous inquiry" (Schön, 1987).*

Schön goes on to argue that the ability to reflect-in-practice is a form of artistry necessary for success in the swampy world of real, complex, ill-structured problems. Cowan (2006), developing his model for reflection, presented two principles: "people who think about how they *do it*, will improve at *doing it*" and "people who think about how well they *do* things and how well they *could do* things are more effective self-directed learners."

Reflecting on one's own thinking and learning is part of the metacognitive process (Sawyer, 2005) and, as alluded to above, is an essential component in the development of expertise and in the actions of professional practice. Thus, it is essential that developing, through explicit practice with feedback, the ability to reflect is a part of learning environments (Bransford et al., 2000). Further, reflection becomes essential as the engineering student begins to understand why design decisions are made and he connects them to the responsibilities of the engineer to society (Dreher, 2015). To connect reflection with Illeris' model of learning, we look to one of his four types of learning. Accommodative learning takes place when learners, in a new environment, reflect on previously established mental schemes to activate a restructuring, resulting in new, more developed mental schemes.

Metacognition

Early work on metacognition was done by Flavell (1979) who defined it as "knowledge and cognition about cognitive phenomena." This is often translated as thinking about thinking. To operationalize metacognition for use in developing learning environments, it can be considered as having two dimensions: declarative and procedural. Declarative metacognition is a person's understanding of a learning task, its requirements, and strategies for accomplishing the task. Procedural metacognition is the person's ability to carry out the strategies. This includes task identification, monitoring the progress of the task, evaluating that progress, and making changes in the procedure as a result of the evaluation (Flavell, 1979). For an engineer to solve the complex and ill-structured problems in Schön's "swamp," performing these metacognitive tasks, accomplished through reflective activities, is essential. It could be argued that these are the same skills and abilities necessary to achieve the innovation levels necessary for adaptive expertise. The importance of metacognition is confirmed in APA principle 5 (Figure 2.11), thinking about thinking – higher order strategies for selecting and monitoring mental operations facilitate creative and critical thinking. Bransford et al. (2000) declare, and provide evidence in support, that metacognition increases the degree to which students can transfer previous learning to new situations. In regards to Illeris' models, metacognition is placed in the content corner and is essential to accommodative learning.

Scaffolding

The idea behind scaffolding in a learning environment is that the learner is treated as an apprentice learning a trade, where the trade is cognition rather than a physical process. The physical apprentice observed the master, then slowly learned the trade under the master's scaffolded guidance. As experience led to skill, the master's scaffolding was slowly removed until no further guidance was required, and the apprentice became the master. Cognitive apprenticeship is a model for learning environments in which teachers are the master and the students are learning through "on-the-job training." Here, teachers "identify the processes of the task and make them visible to students; situate abstract tasks in authentic contexts, so that students understand the relevance of the work; and vary the diversity of situations and articulate the common aspects so that students can transfer what they learn" (Collins, Brown, & Holum, 1991). From a constructivist point of view, scaffolding can be used to promote learners' active participation in the development of their learning goals and provides the learners guidance under which they can construct their new knowledge (Sawyer, 2005). In this type of learning environment, the teachers don't deliver new knowledge, but rather guide and prompt, through questioning, the learner development of the knowledge. In describing environments in which adaptive expertise can be developed, Bransford, et al. (2006) list attributes of scaffolding through cognitive apprenticeship. APA principle #2 addresses the requirement of guidance and inquiry in the development of increasing levels knowledge. Scaffolding, when placed in the Illeris model, would lie on the leg between content and interaction as it is necessary for there to be a social interaction with the guide during the development of knowledge.

Motivation

Motivation is connected to the individual, her experiences and her goals, as well as to context, placing it in the setting of time, place and people (Rogers, 2002). Vanasupa, Stolk, and Herter (2009) argue that since "acquiring new knowledge and skills is recognized as a process of change, largely controlled and internally constructed by the learner," the learner's motivation is central to the initiation, continuation, and magnitude of the learning. There is much to support this in the literature (e.g. Blumenfeld, Kempler, & Krajcik, 2006; Bransford, Vye, & Bateman, 2002; Rogat, Linnenbrink-Garcia, & DiDonato, 2013). Further, the intensity of the learner's motivation is due to an interrelationship between interest, value, and autonomy, and these three components have cumulative interdependence. The more value the learner assigns to a task, the more interested he becomes. The more autonomy in the learning process, the more interest and value (Vanasupa et al., 2009). The choices to engage in and monitor learning are components of self-regulated learning (Boekaerts, Pintrich, & Zeidner, 2005). Thus, higher degrees of motivation lead to higher degrees of self-regulation, and both lead to higher degrees of engagement in active learning. Finally, higher degrees in engagement in active learning lead to higher degrees of mastery of core engineering competencies (Prince & Felder, 2006).

Motivation's importance in the construction of learning and its dependence on social interaction make it a substantial component in the design of the learning environment. APA principles 7,8, and 9 account for the importance of motivation in the likelihood of the learner exerting effort for mastery. Motivation would certainly be in the incentive corner of Illeris' triangle, though, as shown above, motivation is impacted by social interaction and directly impacts cognition.

Situativity

A situative view places knowledge "as distributed among people and their environments, including objects, artifacts, tools, books, and the communities of which they are a part" (Greeno, Collins, & Resnick, 1996). Lave and Wenger presented the social character of learning, presenting it as more than the reception of factual knowledge or information. "Learning is situated in the pathways of participation in which it takes places... situated in the learning activities, communities, cultures and societies in which it takes place" (Lave & Wenger, 1991). Johri and Olds (2011) summarize situated learning. Here, knowing is distributed in the learner's social and cultural world. Learning takes place through engaged participation, social practices of inquiry, practices of formulating and solving realistic problems. Learning environments support the development of positive identity. Students participate in assessment. Further, Johri and Olds connect situativity with the learning of engineering broken down into the use of representations, alignment with professional practice, and emphasis on design. Engineering cognition is based on representations that take on various forms such as words, visuals, and tools. Professional practice includes an identity alignment with the people and cultures of the working communities. Design is activity rooted in collaboration, artifacts, tools, and the contexts in which the design will be employed. This clearly places engineering learning as being "distributed among people and their environments, including objects, artifacts, tools, books, and the communities of which they are a part." In his story Jakob and Manipulator, Henriksen explores the complex interactions between the designer, the environment, and the technology, demonstrating the importance of situativity (Henriksen, 2012). Relating situativity to previously discussed elements, clear connections can be made to motivation and reflection. It is at the core of social/cultural constructivism. APA principle 11 highlights the influence of social interaction on learning. In Illeris' model, situativity is at the bottom vertex of interaction.

Learning Community

Closely related to situativity is the concept of the learning community. Lave and Wenger (1991) pioneered the concept of *communities of practice.* They defined community as that place in which "participants share understandings concerning what they are doing and what that means in their lives and for their communities." They describe participants as "members who have different interests, make diverse contributions to activity, and hold varied viewpoints." A community of practice, then, is the relationships between the people, their activities, and their world through time and with respect to other communities. Participation in learning communities has recently, through research, been linked to increased positive engagement (Zhao & Kuh, 2004). Through engagement, the learning environment element of learning community connects to motivation. This places learning communities on the leg of Illeris' triangle between emotion and interaction. It connects directly and indirectly with APA principles 6, 7, 8, 9, and 11. The social aspect of constructivism implies a community of learners. In conclusion, learning communities are embedded in the fabric of constructivist learning and cannot really be considered as separate; however, in the design of learning environments, special attention can be given to the establishment of community.

Identity

Just as with reflection, identity's value has us considering it in both sections 2.2 and 2.3. Throughout an engineer's education, he builds a concept of himself in relation to the activities and values of his profession. The strength of that concept is considered his professional identity, his personal identification with his career choice. This is a person's perception through the lens of himself and from the continuous feedback from his environment. In engineering education, professional identity has been studied and found to have a positive correlation with student learning (Eliot & Turns, 2011; Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008). Further, Plemmons (2006) makes a case for identity and learning:

> *"When students grow more mature, they become more responsible for their decisions and actions. This results in them becoming more self-directed in their learning and less dependent on their teachers."*

Many educational activities are identified as building positive external (expectations of others about the professional responsibilities) and internal (person's own values as they relate to the profession) identity. Examples include internships (Dehing et al., 2013), service learning (Dukhan, Schumack, & Daniels, 2008), participating in learning communities (Du, 2006) and PBL (Du, 2006).

There is certainly inter-relativity in the previously discussed elements of learning elements of situativity, motivation, learning communities. Situativity and learning community participation have been shown to build identity, and higher identity improves motivation (Lave & Wenger, 1991). Identity through social interaction fits on the right leg of Illeris' triangle, on the line between emotion and environment. APA principles 7-11 involve these interactions between motivation and social learning environment that both impact and are impacted by identity. Dehing (2013) makes the arguments that, because of the importance of identity building, learning environments explicitly develop engineering identity from the very beginning of education, treating students as student engineers as early as possible.

2.3.5. FRAMEWORK FOR CLASSIFYING

We have identified essential components of the learning environment and used the literature to validate their importance. These essential elements are inter-related, and a concept map showing this has been created. Illeris' model has been presented, validated, and given value to. The tensions in Illeris' triangle have been used to place constructivist principles and essential elements in learning environments. In

Figure 2.13, we superimpose Illeris' triangle onto the concept map of learning environment elements to illustrate their respective positions. The Illeris model, principles of constructivism, and elements of learning described above provide the aspects against which models of learning can be evaluated.

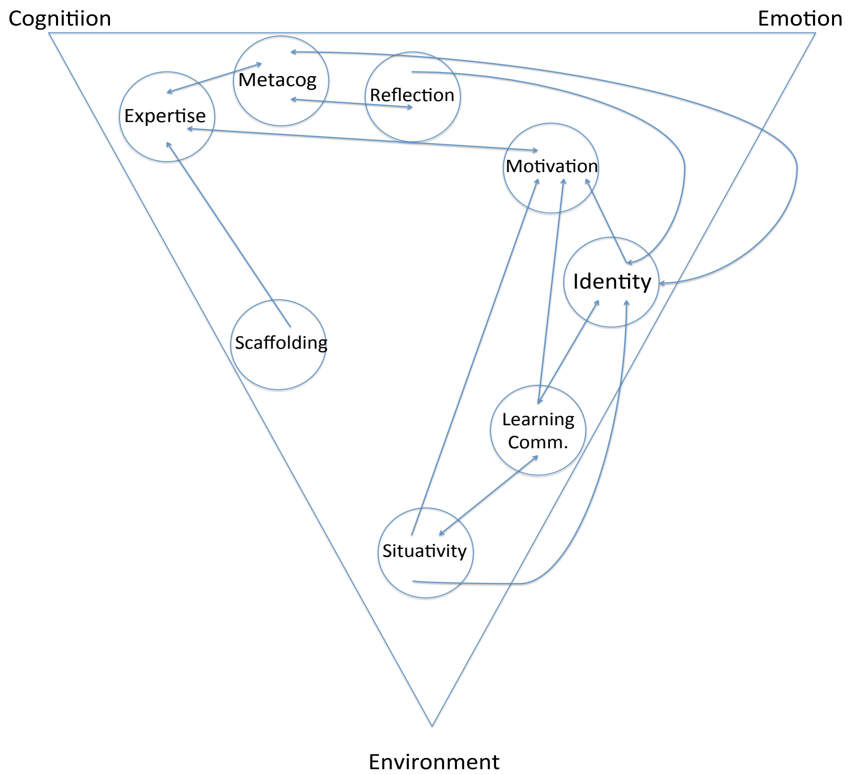

Figure 2.13. Illeris' triangle superimposed onto concept map of learning elements

The purpose of this section has been to provide a theoretical basis to address the objective of analyzing the IRE model through theory. In subsequent sections and chapters, PBL and the Iron Range Engineering model of PBL will be described and analyzed in terms of Illeris' triangle, the APA principles, and the elements of learning and learning environments.

2.4. PBL

With the ultimate goal of this volume being a description and subsequent analysis of the Iron Range Engineering model of PBL, the goal of this section is to provide

PBL theoretical background for *detailing how the IRE program implements the principles of PBL.* The previous two sections took broader looks at curricular and learning theory. The next step is to focus specifically on PBL. We will do this by defining PBL in the literature and placing it in learning theory. Further, we will consider the benefits and critiques of PBL, especially in meeting the calls for change. The final goal of this section, as it was in the previous sections, is to establish a framework for analyzing the IRE PBL model in a future Chapter. A summary of the Aalborg PBL model will be provided as a base model for the development of the IRE model.

2.4.1. DEFINING PBL

Problem-based learning (PBL) has its origins as a core curriculum at McMaster University medical school in the 1970s (Neufeld & Barrows, 1974) and the adaptation of that model at other medical education facilities around the world (Wood, 1994). It's adoption and adaptation continued as Roskilde University and Aalborg University in Denmark, Maastricht University in the Netherlands, and Linköping University in Sweden were founded and established on problem-based learning in the 1970's (Kolmos, Fink, & Krogh, 2004).

Even though problem-based learning models are different as it is practiced around the world, Barrows (1996) identified six core characteristics for all problem-based learning:

- Problems form focus and stimulus for learning
- Problems are the vehicle for development of problem-solving skills
- New information is acquired through self-directed learning
- Student-centered
- Small student groups
- Teachers are facilitators/guides

In engineering education today, PBL is also used to refer to project-based learning. This creates some confusion as to what defines a PBL curriculum. Of particular interest in this study is the Danish approach to PBL, it is considered an approach to PBL that is a "combination of a problem-based and a project-organized approach" (Kolmos et al., 2004). At Aalborg, the traditional model of PBL is based upon problem-based project work.

Prince and Felder (2006) in their study of inductive learning methods sought to clarify a definition for problem-based and project-based learning. They defined problem-based learning as when "students are confronted with an open-ended, ill-structured, authentic (real-world) problem and work in teams to identify learning needs and develop a viable solution." They emphasized the role of the instructor as the facilitator in this process, as compared to one of "information source," which they play in a traditional education model. Further, they defined project-based learning as beginning with “an assignment to carry out one or more tasks that lead to the production of a final product – a design, a model, a device or a computer simulation. The culmination of this project is normally a written and/or oral report summarizing the procedure used to produce the product, and presenting the outcome” (Prince & Felder, 2006).

Based on these definitions, the problem-based learning method is more open-ended than the project-based learning method. Similarly, Savin-Baden (2003, 2007) does a compare and contrast of the two PBL approaches, primarily on the premise that problem-based learning is more process-focused, and that project-based learning is more about the product and is narrower in scope.

These discussion and definitions are primarily about the scope of the problem and projects involved. More important to PBL, for this study, than the scope of the project or problem work is the learning experience they can provide for students “The outcomes of the PBL learning experience are designed to help students:

1) construct an extensive and flexible knowledge base;
2) develop effective problem(project)-solving skills;
3) develop self-directed, lifelong learning skills;
4) become effective collaborators; and
5) become intrinsically motivated to learn” (Barrows & Kelson, 1995).

These potential outcomes make PBL a curricular approach of interest for meeting the calls for change in engineering education. This will be discussed later in this section.

Kolmos (1996) states that “the main idea beyond both project work and problem-based learning is to emphasize learning instead of teaching.” Kolmos et al. (2014) argue that “project-based learning cannot exist without a problem-orientated approach.” They use two definitions to support this understanding of project-based learning. First, the Capraro and Slough (2009) definition, “a well-defined outcome and an ill-defined task. PBL for the purposes here is the use of a project that often results in the emergence of various learning outcomes in addition to the ones anticipated.” The other is the Algreen-Ussing and Fruensgaard (2002) definition of a project as “a complex, unique, and situated task that cannot be repeated and will always involve an open approach.”

The definition of project-based learning we will use, in this study, is that every project starts with a problem (Kolmos, de Graaff, & Du, 2009). The problem may be a curiosity; a contradiction to be resolved; an interest to make something better; a need of a customer to be accomplished; or an industry need to be met. The learning process starts with the problem. The project adds authentic complexity to the problem solving and involves real-world complex solving strategies to solve the problem at the heart of the project. The project adds to the learning process the need to report and have a timeline that reflects the work world students will enter.

This definition will be used in defining project-based learning (PBL) in the remainder of this chapter and thesis. Given their similarity, external discussions and references included in the discussion will include both problem- and project-based learning.

De Graaff and Kolmos (2003, 2007) identified a set of common learning principles based on an analysis of PBL models and the "learning theories that form the basis of both PBL models such as Dewey, Kolb, and Schön" (Kolmos, de Graaff, & Du, 2009). These principles help draft a definition of PBL that is beyond the curricular level and are at a more philosophical and abstract level. They form a set of principles that can cross specific contextual conditions. The identified three approaches to the learning principles are the Learning Approach, the Contents Approach, and the Social Approach, as shown in Figure 2.14. These learning principles will be discussed further within the learning theory discussion of PBL

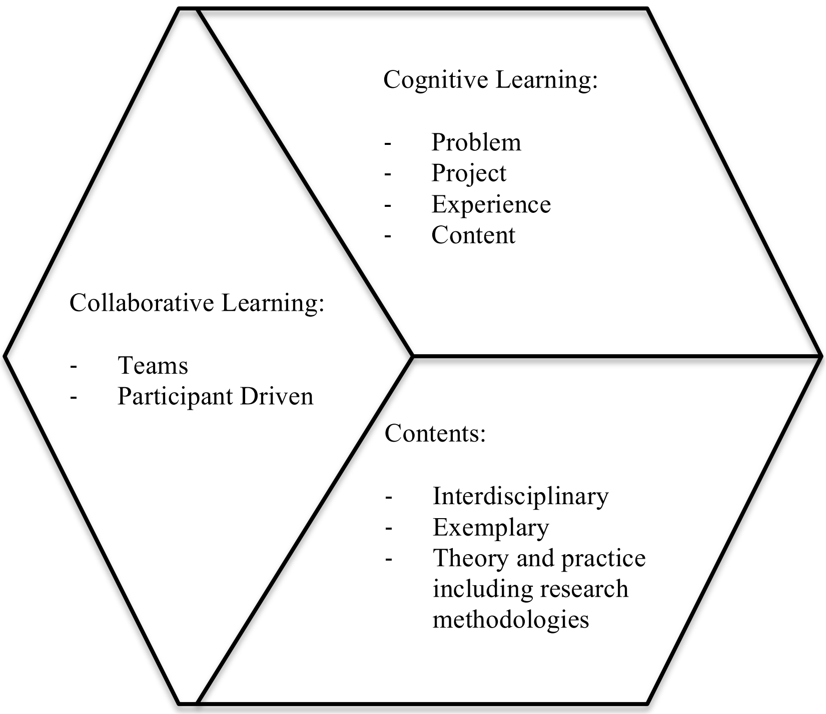

Figure 2.14. PBL learning principles (Kolmos, de Graaff, & Du, 2009)

2.4.2. AALBORG PBL MODEL

Before continuing the discussion of learning principles and learning theory related to PBL, the discussion of PBL will continue with a closer look at the Aalborg PBL model. It served as a basis in the development of Iron Range Engineering.

As mentioned earlier, it is a project-organized; problem-based learning approach to student learning. In 2004, Aalborg University published a book on the Aalborg PBL model. It was the results of an internal conference on the model (Kolmos et al., 2004). In it is a description of the traditional Aalborg PBL model with the following characteristics:

- Founded on problem-based project work – half of the student time is spent on project work and the other spent on lecture/course work.
- Project work is done in teams – in the students' first year, the teams start with six – seven students and reduce to two – three students in the final semester of the students' educational experience.
- Same model for each semester (10 semesters total)
    - Project work supports framework of prescribed learning theme for the semester.
    - 80% of student time is spent on project and related courses. The remainder is spend on fundamental or compulsory courses.
    - Students formulate project proposals.
    - Supervisor approves proposal, responds project progress, and participates in group examination at semester end.
    - Majority of courses must relate to semester theme.
    - Students are to apply coursework to project.
    - Course summative assessment is a group examination.

The curriculum is structured to be fundamentally progressive each semester. As the learning progresses from semester to semester, more flexibility is allowed to the student groups. Projects come from outside entities, such as industry and government or from the personal interests of either the students themselves or faculty. The main focus of the Aalborg model is that the project is at the center of all student learning.

The Kolmos et al. (2004) edited book concludes with a chapter from Joachim Höhle that is written from the perspective of evaluating it from outside the Danish culture. Of specific interest is the discussion of the adaptability of the model outside Denmark. He identifies the need for a short power distance between faculty and the students and flexibility in student evaluation for the model to be successfully utilized. Cultural factors will affect how the model is adapted as it is adopted. The cultural and social factors will be visited in the next section as PBL is positioned in the Illeris model and social constructivism.

2.4.3. PBL IN LEARNING THEORY

Next, PBL is positioned within the theoretical underpinning of the Illeris model, social constructivism, and elements of learning from Section 2.3. (Wilkerson & Gijselaers, 1996) proposed three principals of learning to connect PBL with education learning theory:

1) Learning is a constructive and not a receptive process.
2) Metacognition affects learning.
3) Social and contextual factors influence learning.

2.4.3.1 Illeris Model

As described previously, the (Illeris, 2007) model identifies three dimensions of learning: content, incentive, and interaction. (Kolmos & Graaff, 2014), in their analysis of PBL models and practices, identify three main learning principles: learning approach, social approach, and contents approaches.

Illeris's content dimension focuses on the knowledge and skills that are an intended outcome of a learning approach; this is the "what" of student learning. Connecting the content dimension to PBL, (Kolmos & Graaff, 2014) identify the c*ontents approach* as the identification of the knowledge and skill as the intended outcomes of a PBL curriculum. An <u>exemplary practice</u> for the *contents approach* is students having the "freedom to choose projects within a given theme" (Kolmos & Graaff, 2014).

Second, is the incentive dimension of the Illeris model where the motivations for learning are considered; this is the "why" of student learning. It connects to PBL through the *learning approach* with the utilization of real life projects in which students must identify, analyze, create, and report results. The project or problem "forms a starting point for the learning process, as the problem indicates the purpose of the learning process. This means that students can orient their reading toward this particular problem to gain a deeper understanding" (Kolmos & Graaff, 2014). Critical to the learning approach is the self-directed learning that takes place in the collaborative setting of the team as they negotiate the learning process.

Third, is the interaction dimension of the Illeris model, which considers the interactions that take place during the learning process; this is the "where" and "how" of student learning. It is the social aspect of learning. It connects to PBL through its *social approach* with the team-based learning and the "interaction between the individual and the group" (Kolmos & Graaff, 2014).

2.4.3.2 Social Constructivism

Work in social constructivism suggests that learning occurs with individuals in a social context (Vygotsky, 1978). Project-based learning with individuals in teams working on projects is, by its very nature, social as students seek to create solutions to these projects. An underlying premise is that individuals construct much of what they learn in solving these projects (Schunk, 2009); as knowledge that didn't exist for them before must be constructed while they seek solutions to the projects.

If we look at Jonassen's (1991) five tenets for describing constructivism and connect them with the PBL learning approaches, identified by de Graaff and Kolmos, as shown in Table 2.2, (de Graaff & Kolmos, 2003, 2007), we can see that PBL is fundamentally based upon constructivism assumptions (Marra, Jonassen, Palmer, & Luft, 2014).

Table 2.2. Constructivism tenets and PBL learning principles

Five Tenants for Describing Constructivism - Jonassen	PBL Learning Principles – de Graaff and Kolmos
1. Knowledge is constructed via interactions with the environment 2. Reality (the sense we make of the world) is in the mind of the knower 3. Meaning and thinking are distributed among the culture and community in which we exist and the tools we use 4. Knowledge is anchored in and indexed by relevant contexts Knowledge construction is stimulated by a question or need or desire to know	**Cognitive Learning Approach** - Problem - Experience - Project - Context **Contents Approach** - Interdisciplinary - Exemplary - Theory and practice including research methodologies **Social Approach** - Teams - Participant-driven

Knowledge is constructed via interactions with the environment.

Jonassen (1991) describes humans as learners that perceive and interpret as they construct an interpretation of the world around them. Through this cognitive and interpretive process, they construct new mental models as they try to make sense of accommodating existing beliefs and knowledge representations with the new ideas, phenomena, and ways of understanding.

If we look at PBL, the utilization of projects creates an authentic environment or context where students need to construct new knowledge. As part of the *cognitive learning approach,* the problem to be solved serves as "the starting point for the learning process." The project aspect adds more complex strategies that will challenge students to acquire new knowledge and understanding to solve these more complex challenges. The project aspects of doing a real world project, working with a team, developing a final report, and having a deadline to meet all add the authenticity that makes PBL an effective learning approach.

<u>Reality (the sense we make of the world) is in the mind of the knower.</u>

Jonassen (1991) states the sense-making process is something that is unique to each learner. Contrary to the linear, consistent approach of traditional educational processes, each learner has a perception of the external world around her and therefore has a set of learning experiences that is unique to them as an individual. This does not mean that the process cannot be communicated and expressed to others, but it does mean that the process cannot be readily transmitted or acquired by others in a duplicate fashion.

If we look at PBL, this is reflected in both the *cognitive learning* and *contents approaches*. Since the problem serves as the starting point for learning, it allows each learner to start with their current understanding of the external world, specifically, in the context of the particular problem to be solved. As solutions are sought to the problem, as part of the project work, the individual must evaluate their own current models and determine if they are adequate for use with the particular problem. If they are not, then the individual must go through a unique set of learning experiences to add to, or adapt, these models to a level adequate for the particular problem.

Given the interdisciplinary nature of the *contents* of a problem, the learning will span across the "traditional subject-related boundaries and methods" (Kolmos, de Graaff, & Du, 2009). This *contents approach* to PBL allows the individual knower to access all models and work across the discipline boundaries as he seeks a method to solve the problem.

<u>Meaning and thinking are distributed among the culture and community in which we exist and the tools we use.</u>

Jonassen (1991) proposes that as an individual engages in a learning community, the beliefs and values of that community influence the individual's own knowledge and beliefs. Cunningham and Duffy (1996) define this learning as changes in how an individual understands the external world as it relates to, or in relation to, the culture to which the individual is connected.

If we look at PBL, this plays out particularly well with the *social approach* of the team-based learning within the problem solving for the project. It is best summarized by:

> *"The team-learning aspect underpins the learning process as a social act where learning takes place through dialogue and communication. Furthermore, the students are not only learning from each other, but they also learn to share knowledge and organize for themselves the process of collaborative learning. The social approach also covers the concept of participant-directed learning, which indicates a collective ownership of the learning process and, especially, the formulation of the problem"* (Kolmos, de Graaff, & Du, 2009)

It is through this social process of collaborative learning that the individuals learn and grow in their understanding of the external world. At the same time, their knowledge and beliefs are distributed to their teammates as fellow participants in the learning community (Salomon, 1993).

<u>Knowledge is anchored in and indexed by relevant contexts.</u>

Jonassen (1991) explains that, in the constructivism viewpoint, our ideas and skills consist, at least partly, in the situation or context where they were acquired or applied. In contrast, the ideas, concepts, rules, and laws that are learned in the abstract, separate from any context, have no real value or meaning. This approach can be at least partially attributed to traditional methods of instruction within engineering, where students "learn" a new concept through a lecture in which a professor goes through a mathematical derivation to derive the equation. Although one could argue that the mathematical proof provides context, the abstractness of this context is beyond where most undergraduate students are in their learning abilities. The mere teaching of facts and concepts, without context, prevents meaningful indexing of them by the individuals learning them. Without context, there is no indexing of learning to the features of a current or future application, where it may be relevant (Schank, Fano, Bell, & Jona, 1994).

If we look at PBL, the entire *cognitive learning approach* is based on the premise that learning takes place in the context of solving a problem as part of the project. Not only is there the immediate context of the problem to index the learning, but the recognition of the problem within the overall project and the determination of relevant solutions and pertinent information provides a much deeper level of anchoring and indexing for the individuals involved in the process.

<u>Knowledge construction is stimulated by a question or need or desire to know.</u>

Jonassen (1991) explains that, within the constructivist understanding of the construction of knowledge, the acquisition of knowledge occurs through the dissonance between what an individual "knows" internally and what he is observing in the external world around him. Although things shared by others can be memorized, the dissonance truly comes when the learner is actively involved with making meaning of the difference between what is currently "known" by the individual and what the individual needs to or wants to know.

If we look at PBL, this is reflected in both the *collaborative learning* and *contents approaches*. The learning is participant-driven as they seek solutions to the problem they are trying to solve. The learning occurs when they recognize what is "known" is not adequate to solve the problem. This recognition creates the need or desire to know or understand the knowledge required to solve the problem and develop a solution for the project. The *contents approach* of PBL emphasizes the relationship between theory and practice in the problem approach. As the learner uses the analytical approach to solving the problem, a theory must be utilized as the heart of the approach. Each problem causes the learner to grow in his understanding of the theory through the necessary process of relating or adapting it to each unique application. Kolmos, de Graaff, & Du (2009) point out that this facilitates the individual's training in research methodologies.

2.4.3.3 APA Principles

The APA principles for effective learning are, for the most part, social constructivist in nature. Connecting these principles to PBL, they are used to ground aspects of the PBL learning. The first five *cognitive and metacognitive factors*: 1) nature of the learning process, 2) goals of the learning process, 3) construction of knowledge, 4) strategic thinking, and 5) thinking about thinking ground the learning occurring in the context of the project. The complexity of the projects creates an intentional learning process that requires students use higher order strategic thinking strategies to identify learning goals for developing new knowledge to complete the project and then link this with previous knowledge with new knowledge.

The *motivational and affective factors*: 7) motivational and emotional influences on learning, 8) intrinsic motivation to learn, and 9) effects of motivation to learn, are connected to the genuine experience created by the project. Students enter engineering to become engineers, the curiosity, and motivation that led students to make the decision to enter the study of engineering is positively affect by the novelty and difficulty of the projects when students have a choice in selecting the project and control over the learning process within the project. This in turn has a positive effect on creating a strong, natural intrinsic motivation for what and how much is learned.

In regards to the remaining principles, the social interactions, interpersonal relations, and communication within the team environment directly relate the PBL curriculum to the APA principles 6) context of learning and 11) social influences on learning. As discussed earlier relating to the Illeris dimensions of learning, PBL learning is within and across the physical, intellectual, emotional, and social domains of APA principle 10) developmental influences on learning. The *individual differences factors* are not necessarily connect to the PBL curriculum, but each individual student experience is still grounded in them as they traverse the curriculum.

2.4.3.4 Elements of Learning and Learning Environments

These elements, development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity, were then constructed into a concept map that was superimposed on the Illeris triangle. We will make an initial underpinning of these elements to PBL; in a later section, we will specifically connect them to the development of the new PBL model.

<u>Development of Expertise</u>

Experts, as compared to novices, tend to organize their knowledge around the fundamental principals of their domain of knowledge. PBL supports this element in that the approach to solving the problem in the project requires the learners to first determine the fundamental principal of importance to solve the problem. The interdisciplinary nature of the PBL work does not make the selection of the fundamental principle an arbitrary one. This facilitates the life-long process of the student developing expertise, and the approaches that an expert takes in problem solving.

In contrast, traditional educational approaches, at least within engineering education, make the identification of "which fundamental principal to use" very much an arbitrary decision. In fact, most times, there isn't necessarily even a recognizing of the fundamental principal, but more an organizing of knowledge around "what solution do I use with this type of problem?" This hardly creates an environment to foster the development of expertise.

<u>Reflection</u>

Schön's argument for the ability to reflect-in-practice as an art form for success in the swampy world of real, complex, ill-structured problems is an integrated part of the problem-solving process of PBL. As learners work on the problem and interact with their teammates, they constantly have to reflect on their current internal understanding as it compares to the understanding communicated by others and the reality of the external, real-world system with which they are dealing. Through this critical part of the PBL process, students practice and develop the ability to reflect-in-practice for future professional practice.

Metacognition

Metacognition, often translated as "thinking about thinking," has two dimensions: the declarative dimension and the procedural dimension. Declarative metacognition, an individual's understanding of a learning task, is an integral component of PBL problem solving. Given the ill-structured nature of the problem to be solved within the project, the students must continually reflect on their individual and overall team understating of the problem and the strategies being used to solve the problem, and also whether the understanding and strategies are still currently correct.

Procedural metacognition, a person's ability to carry out strategies, is also an integral component of PBL problem solving. As each problem, to be solved within a project, is unique in how it will be solved, each learner will need to identify tasks specific to the project, monitor the progress of the task, evaluate that progress, and make changes in the procedure as a result of the evaluation. If the learner identifies a task that she does not know how to accomplish, she has created an authentic learning opportunity to gain the knowledge necessary to complete the given task.

Scaffolding

From a constructivist point of view, scaffolding can be used in PBL curriculum to promote learners' active participation in the development of their learning goals and provide guidance under which they can construct their new knowledge. Within the project work, instructors don't deliver new knowledge, but rather guide and prompt, through questioning, the learner development of the knowledge to solve the problems. Given the uniqueness of the learning process for each individual and the uniqueness of each problem, the instructor must provide the correct amount of guidance and prompting to allow the learning and work to move forward, but must, at the same time, allow for it to be a student-driven process. The amount of scaffolding will reduce as the learners are better able to access their own learning and increase their ability to learn new knowledge.

Motivation

As identified previously, the learner's motivation is connected to the individual, his experiences and goals, as well as to the learning context, the setting, time, place, and people. The *collaborative learning approach* of PBL creates the context that learning is carried out on a project that the student was part of selecting, along with a team that he was part of creating. The participant directed nature of the work creates the ideal context for student motivation due to the interest, value, and autonomy the student has in the process. The more value the learner assigns to the task; the more interested the student becomes. The more autonomy in the learning process, the more interest and value.

Situativity

Situativity is at the bottom vertex of interaction in the Illeris triangle model. The environment in which the learning takes place supports the student development of identity. The authentic nature of the problem solving within the project work creates a learning environment that closely reflects the professional environment in which students will find themselves.

Learning Community

The concept of learning community is closely related to situativity. The social aspect of constructivism implies a community of learners. A PBL program provides a larger community of multiple students who are all engaged in the process of becoming something, in this case, engineers. This larger community is embedded in the fabric of constructivist learning. It provides a social aspect for all learners going through a growth process at similar stages of their learning. The teams themselves provide an additional and closer knit learning community for the learner. Even though each learner experiences an individual learning process, the learning experiences of the project team-mates will closely align with each of the individuals on the team. The multiple learning communities provided by project-based learning creates motivation for each learner, as well as a positive engagement by each learner.

Identity

As identified earlier, there is a positive correlation between student learning and the development of the learner's professional identity as she builds a concept of herself in relation to the activities and values of her profession within her engineering education experience.

As we have positioned project-based learning within learning theory using the Illeris model, social constructivism, and elements of learning from Section 2.4, we now turn the discussion to critiques and evaluations of PBL.

2.4.4. PROJECT-BASED LEARNING BENEFITS AND CRITIQUES EVALUATIONS

Both the 2010 and 2013 UNESCO reports on engineering identify the potential of PBL for meeting the needs of the profession and the society today and into the future. Several other prevalent publications identify the use of PBL as a critical component of transforming engineering education (Du, 2006; Felder & Brent, 2003; T. Litzinger, Lattuca, Hadgraft, & Newstetter, 2011; Sheppard et al., 2009).

The 2010 UNESCO Engineering: Issues Challenges and Opportunities for Development report on engineering development identifies a comprehensive list of the several benefits, from the literature, of PBL for students learning and also for the institution as a whole. The positive effects of the PBL model for identified student learning are:

- "Promoting deep approaches to learning instead of surface approach
- Improving active learning
- Developing criticality of learners
- Improving self-directed learning capability
- Increasing the consideration of interdisciplinary knowledge and skills
- Developing management, collaboration and communication skills
- Developing professional identity and responsibility development
- Improving the meaningfulness of learning"

The positive effects identified for the institutions with a shift to a PBL model:

- "Decreasing drop-out rates and increasing rate of on-time completion of study.
- Supporting development of new competencies for both teaching staff and students.
- Promoting a motivating and friendly learning environment.
- Accentuating institutional profile"

All of these positive effects make PBL an attractive curricular approach in the development of the new engineering program. Of particular interest for this research work is the improvement in the self-directed learning capability, the development of management, collaboration and communication skills, and the development of professional identity.

Of particular interest is the 2002 Danish government report that 59% of private employers prefer the PBL graduates from Aalborg vs. graduates from other non-PBL universities. The PBL graduates were identified to teamwork, innovation, and project management skills and a better ability to acquire new knowledge. The UNESCO report also references a survey conducted by Danish Industry in 2004 that showed "graduates from (Aalborg) and from another traditional university have no significant differences in professional knowledge and skills, however, (Aalborg) graduates have a visibly better performance in skills of project and people management, communication, innovation, knowledge of business and life" (*UNESCO, ENGINEERING: Issues, Challenges and Opportunities for Development*, 2010).

Despite the potential for PBL, it is not without its critiques as to its effectiveness as an educational approach. Kirschner, Sweller, and Clark (2006) critiqued the effectiveness of PBL, along with several pedagogical approaches grouped together under the category of minimal guidance instruction. Although they specifically referenced problem-based learning, their definitions and arguments are applicable to project-based learning as well.

Kirschner's and his colleagues' argument is that although minimally guided instructional methods, such as PBL, are "very popular and intuitively appealing," they ignore what is understood about human learning and evidence from studies of student learning. They argue that "direct instruction guidance" is a more effective and efficient education model.

They highlight two underlying assumptions with "minimal guidance" models. First, "they challenge students to solve 'authentic' problems or acquire complex knowledge in information-rich settings." The second assumption identified is "that knowledge can best be acquired through experience based on the procedures of the discipline." They identify, we feel correctly, that this is a constructivist instruction viewpoint of learning.

Kirschner, et al. (2006) specifically point to the need for learners to search for information in the "problem space" that is relevant to what they are supposed to be learning. They argue that this places a high load on the individual's working memory with minimal contribution to long-term memory. They define changes in long-term memory as the core aspect of the individual's learning.

To support their arguments, they cite the review work of Mayer (2004) on several studies comparing "guided forms of instruction" to "unguided, problem-based instruction." Mayer concludes his analysis of studies from the 1950's-1980's with "debate about the discovery has been replayed many times in education, but each time, the evidence has favored a guided approach to discovery."

Kirschner, et al., conclude that "may be an error to assume that the pedagogic content of the learning experience is identical to the methods and process (i.e. epistemology) of the discipline being studied and a mistake to assume that instruction should exclusively focus on application." They argue it is time to abandon constructivism and return to more guided approaches, such as worked examples and process worksheets.

Although Kirschner does make some strong arguments regarding how individuals learn, they take a simplistic viewpoint of constructivist education methods such as problem- or project-based learning. Specifically, they err in grouping them in the category of minimally guided instruction (Hmelo-Silver, Duncan, & Chinn, 2007) with other pedagogical approaches. The 2007 rebuttal of the Kirschner, et al., article by Hmelo-Silver, et al., specifically points to the ignoring of the scaffolding of learning that can take place in problem-based learning.

Not only does scaffolding help guide the novice through the complex learning process, Hmelo-Silver et al. (2007) identify that it "may also problematize important aspects of students' work in order to force them to engage with key disciplinary frameworks and strategies." It makes the disciplinary thinking and strategies explicit. Sheppard et al., (2009) in Educating Engineers, identified the use of scaffolding within a spiral-learning model as a critical element to reforming engineering education.

Hmelo-Silver et al., (2007) point out that scaffolding also addresses the high cognitive load issue from the Kirschner (2006) argument. It also provides an authentic approach for instructors to embed their expert guidance and knowledge.

Although the Kirschner, et al., article does raise some valid concerns regarding minimally guided instruction, we argue that project-based learning, with the use of scaffolding to reduce cognitive load, embed expert guidance, and to make explicit the disciplinary thinking and learning strategies, addresses those concerns and allows for a PBL instruction model to take full advantage on a constructivist model of student learning. The arguments and evidence presentment by Hmelo-Silver (2007) appear to support this viewpoint.

An earlier review of problem-based learning by Norman & Schmidt (1992), sought to evaluate the evidence to identify if there was support for many of the claimed advantages for PBL's effect on student learning. They looked at the specific claims of increased student motivation; problem-solving skills; ability as self-directed learners; ability to learn and recall information; and ability to integrate knowledge into actual application.

They identified that there was sufficient support for PBL in the literature to increase students' motivation and abilities claimed. A review of experimental evidence to support each claim was conducted. Norman and Schmidt concluded that:

> *"(1) there is no evidence that PBL curricula results in any improvement in general, content-free problem-solving skills; (2) learning in a PBL format may initially reduce levels of learning but may foster, over periods up to several years, increased retention of knowledge; (3) some preliminary evidence suggests that PBL curricula may enhance both transfer of concepts into clinical problems; (4) PBL enhances intrinsic interest into clinical problems; (5) PBL appears to enhance self-directed learning, and this enhancement may be maintained."*

In this review, they identified key components to a PBL curriculum:

- Students benefit from working through the problem versus a rote fashion
- Students receive immediate corrective feedback regarding incorrect concepts

The critiques do point out the need to focus on some key curricular aspects in the development of the new PBL programs. First, there is a need for scaffolding with embedded expertise to reduce the potential for too high a cognitive load for students. The scaffolding should make the learning of disciplinary thinking and strategies explicit. Second, students benefit from struggling through the problems or projects, but immediate corrective feedback is needed regarding incorrect concepts if students are to take advantage of the PBL instructional approach.

It is clear that there is tremendous possibility with a PBL curriculum to support student learning and provide them with the abilities that are desired by industry. Next the PBL curricular elements will be developed, which will serve as the framework for the curricular decision that will be made in the curricular development.

2.4.5. FRAMEWORK FOR CLASSIFYING PROJECT-BASED LEARNING AND CURRICULAR ELEMENTS

A PBL curriculum model has been developed that creates a framework, which is based on PBL learning principles and curriculum theories of alignment and social construction (Kolmos, de Graaff, & Du, 2009; Savin-Baden & Wilkie, 2004; Savin-Baden, 2003, 2007), for understanding an existing or developing a new PBL curriculum. The seven curricular elements of the model are shown in Figure 2.15:

- objectives and outcomes,
- types of problems, projects, and lectures
- progression, size and duration,
- students' learning,
- academic staff and facilitation
- space and organization, and,
- assessment and evaluation" (Kolmos & Graaff, 2014)

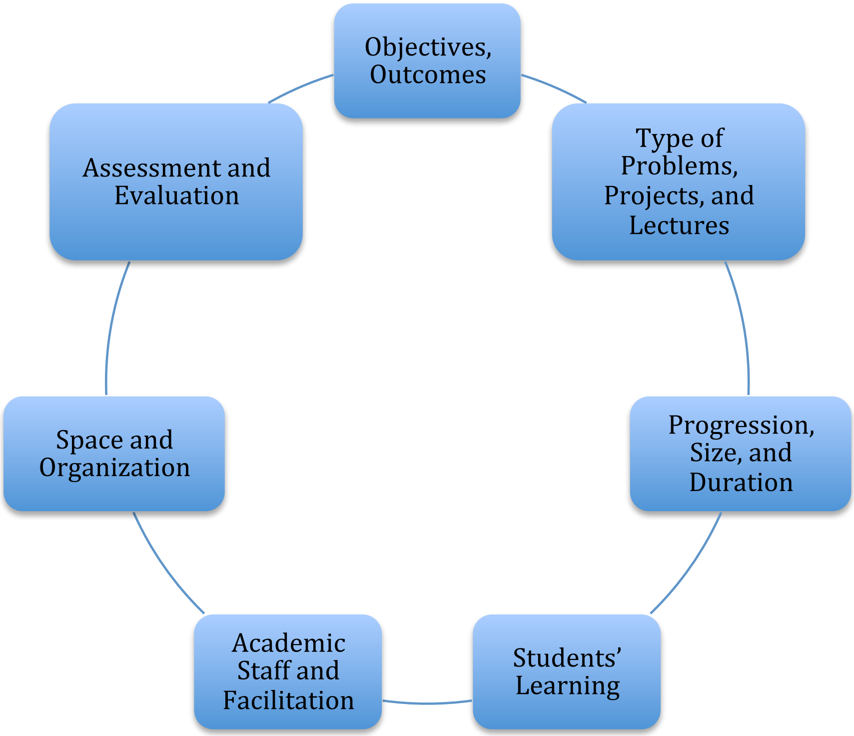

Figure 2.15. PBL Alignment of elements in the PBL curriculum

(Kolmos, de Graaff, & Du, 2009)

Each of the elements of this PBL curricular model has a broad spectrum from "a teacher-controlled on the one side to an innovation and learner-centered approach on the other side" (Kolmos & Graaff, 2014). Between each of the ends of this spectrum are several degrees of varying, mixed approaches that can be applied in the development of a PBL curriculum. Kolmos and de Graaff note that the "principle of alignment is an underlying assumption." A change in one element has an affect on all of the other elements as they are holistically aligned to facilitate the student learning of the program objectives and outcomes. Each of the elements will be described and the characteristics of each spectrum end identified. They will be used in Chapter 3 to characterize and analyze the Iron Range PBL model and in Chapter 4 to describe and analyze its process of development.

Objectives & Outcomes

With any curricular model, it is essential to identify the objectives of the curricular model; defining what the curriculum is trying to accomplish; and what knowledge or learning outcomes there are for graduates of the program. Defining and agreeing upon the learning objectives for the program is a critical part of the vision-casting of the change process described in Section 2.2. The 2011 Royal Academy of Engineering study of curriculum change identified defining the outcome elements as a critical part of the successful change processes (Graham, 2012b).

The spectrum for this element begins on the *discipline and teacher-controlled approach* end; it is expressed by learning objectives being very specific to the discipline itself. The knowledge content is, also, focused solely on that content that is pertaining to only the discipline itself (Kolmos, de Graaff, Du, et al., 2009). This is contrasted with the *Innovative and learner-centered approach* for this element, which focuses on interdisciplinary knowledge and methodological approaches associated with PBL (Christensen, Henriksen, & Kolmos, 2006).

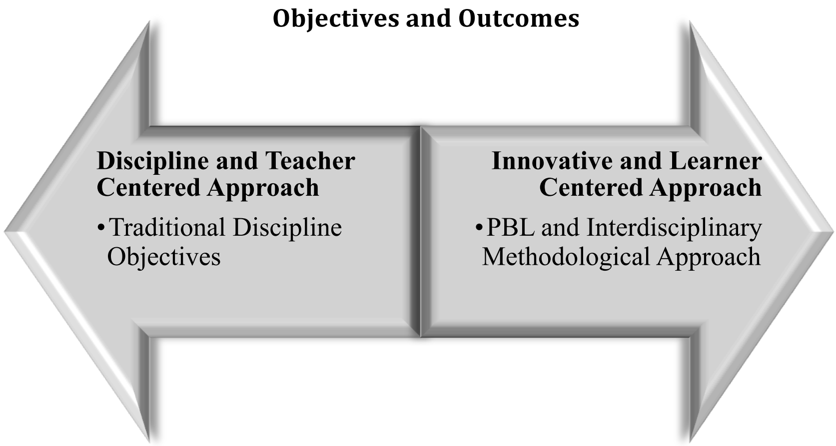

Figure 2.16. Objectives and outcomes spectrum

Types of Problems, Projects, and Lectures

The types of problems, projects, and lectures that students experience, and on which they practice, relates directly to the curricular objectives and graduate outcomes. In the *discipline and teacher-controlled approach* part of the spectrum, the closed-ended problems are well defined with specific steps to a solution and a specific answer. At the other end of the spectrum is the *Innovative and learner-centered approach.* Here, projects are ill-defined, leaving both approach and final solution to be determined by the teams and their students. These types of projects support the interdisciplinary approach of PBL.

Lecturing is part of the whole spectrum; however its focus, content, and duration adjust based upon the type of problem and project work students are doing. In the *discipline and teacher-controlled approach,* lectures focus on knowledge transfer from the expert to the student. In the *Innovative and learner-centered approach,* the lectures need to support the project. The emphasis shifts from knowledge transfer to guiding students through the knowledge acquisition process, as directed by their project work.

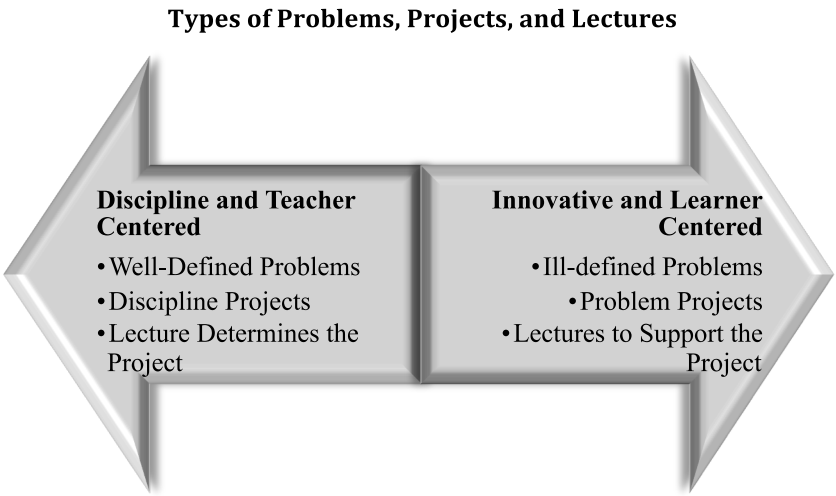

Figure 2.17. Types of problems, projects, and lectures spectrum

Progression, Size, and Duration

One of the initial characteristics of the progression of PBL is the percentage of time committed to project work or the size of the project work within the curriculum. On the *discipline and teacher-controlled approach* end of the spectrum, the project work is relegated to a minor part of the curriculum. It could be an add-on to one or more courses and serve as a capstone senior design project.

As the profession moves towards the *Innovative and learner-centered approach* end of the spectrum, the projects consume more and more time within the curriculum. As the time dedicated to projects increases, so does the impact the project work has on student learning. The learning outcomes that can be achieved in the PBL curriculum are dependent on this time commitment, as the learning takes time within the project work.

Savin-Baden (2000, 2007) proposed five models of PBL, focusing on the objective of the PBL model and the perceptions pertaining to knowledge, learning, problems, students, teacher roles, and assessment. It is not intended that one model is preferred over another; what matters is that the model that best facilitates students meeting the desired learning outcomes of the program is selected. The problem approached is at the center of the projects within the developed definition for project-based learning.

> *Model 1: PBL for Epistemological Competence* – the problem (or project) is very narrow in this model with knowledge attainment focus more or less propositional within a narrow problem scenario. This model represents the end of the project scale that is characterized by having a set or narrow problem (or project) process and final solution option.
>
> *Model 2: PBL for Professional Action* – the problem (or project) is characterized by real-life situations with a knowledge attainment focus that is practical and performance-oriented.
>
> *Model 3: PBL for Interdisciplinary Understanding* – the problem (or project) is situational with a problem scenario that requires a combination of theory and practice, with knowledge attainment focus that is propositional, performance-oriented, and practical.
>
> *Model 4: PBL for Trans-disciplinary Learning* – the problem (or project) scenario consists of dilemmas that require students to use different disciplinary knowledge. The aim of this model is to test the knowledge of the team.
>
> *Model 5: PBL for Critical Contestability* – the problem (or project) scenario is open and multidimensional in the possible focuses and approaches, with the knowledge attainment focus contingent on the project, and will be contextual and constructed by the learner for given situations.

All five models represent the variability that can exist in problems (or projects) to facilitate student learning. The commonalities are the:

- "learning is organized around problems (or projects)";
- "problem is the incentive for the learning process and is a central principle to enhance students' motivation";
- "importance of problems the students are attracted to on the basis of their own experiences and interests. It could be any type of problem (or project); it could be a concrete and realistic problem or a theoretical problem"; and

- most importantly, "problem reflects the conditions of professional practice. Therefore, it makes sense that, in some instances, cases are relatively short, providing study materials for half a week, and in other instances, a project could last half a year" (de Graaff and Kolmos, 2007).

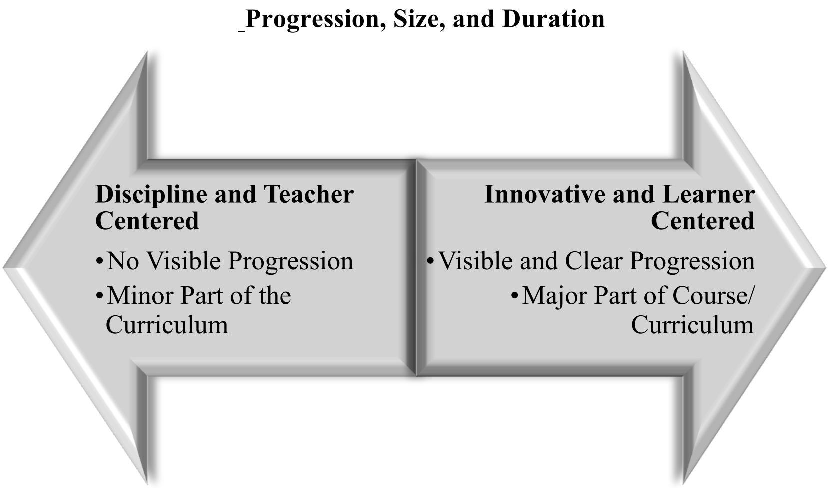

Figure 2.18. Progression, size, and duration spectrum

Students' Learning

Students generally enter their engineering curriculum with little to no experience or training for function as a team or how to manage projects. This is a critical part of the PBL curriculum; what are the expectations that the students have?

The types of problems, projects, and lectures that student experience, and on which they practice, will relate directly to the curricular objectives and graduate outcomes. In the *discipline and teacher-controlled approach* end of the spectrum, the closed-ended problems are well defined with specific steps to a solution and a specific answer. At the other end of the spectrum, in the *Innovative and learner-centered approach,* projects are ill-defined, leaving both approach and final solution to be determined by the teams and their students. These types of projects support the interdisciplinary approach of PBL.

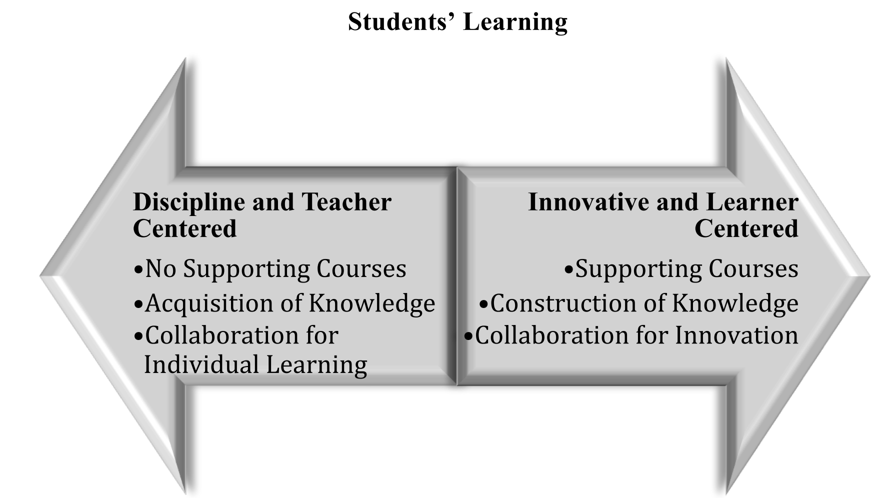

Figure 2.19. Types of students' learning spectrum

<u>Academic Staff and Facilitation Element</u>

Critical to any curricular model is the role of the academic staff in facilitating and guiding student learning. In most models of education, faculty are left, for the most part, to their own expertise and efforts to find ways to facilitate learning within the traditional lecture course model. In most cases, faculty will utilize the methods that they are familiar with from their own undergraduate and graduate experiences.

In a PBL curriculum, the model of facilitating student learning is a contrast to what they experienced in their own education. Successfully changing to the PBL curriculum is dependent on the academic staff receiving training to develop effective methodologies in facilitating the student construction of knowledge in the team or groups settings of the projects. The role of facilitator or guiding the process of the teams will be new to most, if not all, of the faculty. Training will be needed for the team process to be successful. If the change to PBL is to have longevity, the change theory discussion, from earlier in this chapter, would point to this development not being a one-time event but an ongoing part of the PBL program culture.

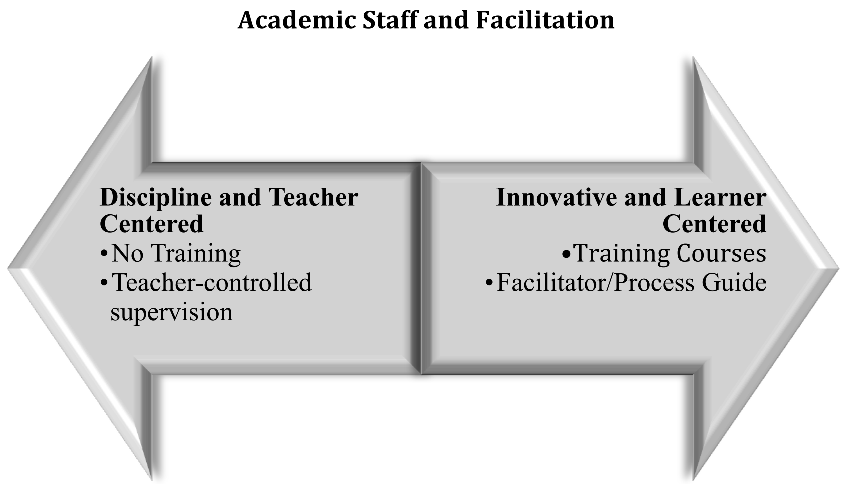

Figure 2.20. Academic staff and facilitation spectrum

Space and Organization

Just like the academic staff need training to transition to supporting the new curricular model, so does the physical space and the institution's organization (de Graaff & Kolmos, 2007). Space needs to be made available that supports the team activities and the project work. The organization needs to develop and recognize that the PBL curriculum will need to be supported in a different way than a traditional program would.

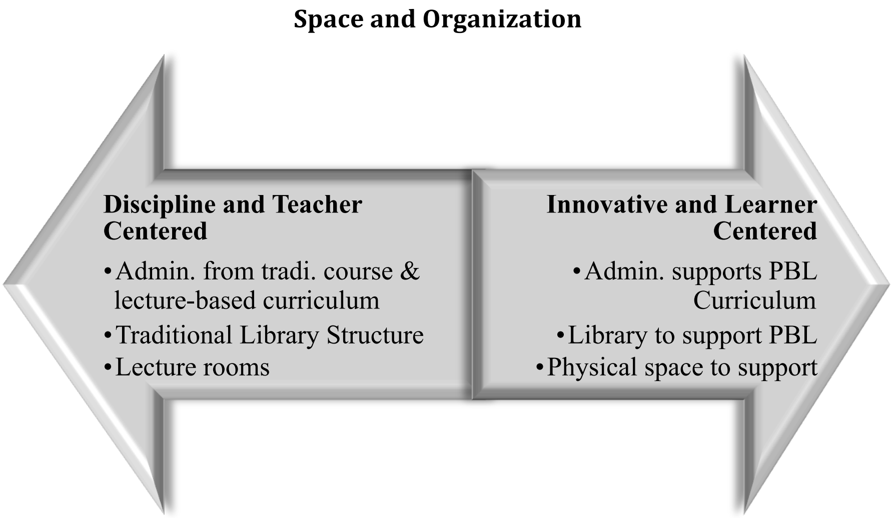

Figure 2.21. Space and organization spectrum

Assessment and Evaluation

Assessment and evaluation of student learning will need to adapt to support the PBL curriculum. There needs to be alignment between the program outcomes and the development of assessment methods that support the student attainment of the outcomes. Whether assessment is taking place on an individual or team basis is an important decision in the development of the program. As with any curriculum, whether the evaluation is going to formative or evaluative is another important consideration. Student involvement in the development of the assessment and evaluation decisions is an important part of student autonomy and commitment to the new education model.

Space and Organization

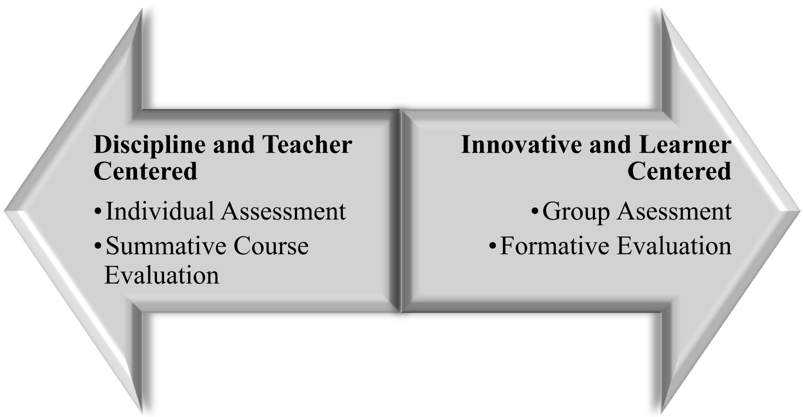

Figure 2.22. Assessment and evaluation spectrum

The purpose of this section has been to provide a theoretical framework for a PBL curriculum. The principles of PBL have been described and placed within the learning theory. The curricular elements have been identified for the development of the PBL curriculum. In subsequent chapters, the framework will be used in describing the Iron Range Engineering model of PBL.

Key Finding: ***This spectrum-based framework will be applied to analyze the Iron Range Engineering model in Chapter 4. It also creates a taxonomy structure for analyzing and comparing PBL curricular models. The intent is to not rank models in comparison to one another but to provide individuals involved with curricular change decisions a way to better understand different curriculums as PBL is applied in different social and education contexts.***

2.5. CONCLUSION

Chapter 2 has developed the change, curriculum, learning, and PBL theoretical perspectives that serve as the basis for the development and implementation of the Iron Range Engineering program. The Organization Change Model and Curriculum Change Model provide both a process for overall organizational change and for a curricular change to PBL. The curriculum perspective was considered from three viewpoints (curricular structural elements, a classification framework, exemplary curricular) to develop an extensive set of curricular criteria to be used in developing the new PBL curriculum. The learning theory perspective has been developed to use Illeris' triangle, the APA principles, and the elements of learning and learning environments in describing PBL and the Iron Range Engineering model of PBL. The PBL theory was explored to identify the curriculum elements for the development of the Iron Range Engineer PBL program.

Chapter 3 will develop a historical description of the development and implementation of the PBL curriculum. The change theory perspective will be used to analyze this process. Chapter 4 will describe the current program and analyze it within the learning, curricular, and PBL theoretical perspective developed in this chapter.

CHAPTER 3. HISTORY

(RON ULSETH AND BART JOHNSON)

3.1. INTRODUCTION

The idea of the Iron Range Engineering program began in the early 2000's as a dream and progressed to the present day as the program was invented, developed, adapted, and evolved. The narrative is viewed through the lenses of two perspectives, the 8-step model for change (Froyd et al., 2000), along with the dual layers of educational change from the curricular and organizational viewpoints (de Graaff & Kolmos, 2007). They were discussed in Chapter 2 and provide a perspective through which to analyze the history of the Iron Range Engineering program.

3.2. ITASCA COMMUNITY COLLEGE

Iron Range Engineering had its beginnings in Itasca Community College; a lower-division engineering program. In the United States, a four-year bachelor of science engineering degree is split between lower division, the first two-years and first 64 credits, and upper-division, the second two-years and final 64 credits. The focus of the first two years is primarily on foundational science, math, and general education courses with some focus on introductory engineering courses. It is not until the second two years, the upper-division, that students truly enter an engineering program such as mechanical, electrical, chemical, biomedical, etc. The first two years have been referred to as the "math-science death march" (Goldberg, 2014). The attrition of students in the models is staggering; approximately 40% of students who start with engineering in their first year of college will ultimately complete a bachelor's degree in engineering (Department of Education, 2009).

Students can either complete their lower-division learning at a university, or they may choose a two-year community college. In community colleges, students earn an associate's degree and then transfer to a larger four-year university to complete the bachelor's degree. Community colleges are a substantial segment of the pathway to students completing a bachelor's degree in engineering. Roughly 50% of practicing engineers attended a community college on their educational pathway to becoming an engineer (NSF, 2015).

It is with this background that the Itasca Community College engineering program story begins. Itasca is a small, rural, two-year community college. In 2015, Itasca enrolled approximately 1000 full-time students (itascacc.edu, 2015). It is located in the town of Grand Rapids (~15,000 residents), in northern Minnesota in the United

States of America, approximately 80 miles northwest of Duluth. The college serves students primarily located in the northern third of the state. The institution was founded in 1922. It is a member of the Minnesota State Colleges and Universities system and the Northeast Minnesota Higher Education District. The institution has held accreditation with the North Central Association Higher Learning Commission since the mid-1970's.

In the 1980's, the college had few engineering students taking math and science courses with the intent of transferring those courses, in the above-mentioned fashion, to a regional four-year university that had an engineering program of interest to them (Ulseth, 2004). Itasca physics instructor Aaron Wenger identified that there had to be a better way to instruct future engineers than the model that existed at that time.

As other faculty joined Aaron, the program grew from 10 students in 1993 (Ulseth, 2004) to a nationally recognized program (National Academy of Engineering, 2005), with well over 150 students in 2010, learning in a progressive learning community model (Johnson, et al., 2011). The authors joined the faculty of Itasca's engineering program in 1992 (Ulseth) and 2004 (Johnson).

The success of the ICC engineering program was based on six main program elements (Johnson, et al., 2011). These elements each focus on developing students to be successful in their upper-division program, and more importantly, in their engineering careers. It is these elements and this success that served as the baseline philosophy and experiences that enabled the authors to start the Iron Range Engineering program. The six elements are described in detail below.

3.2.1. STRONG RELATIONSHIPS WITH FEEDER PROGRAMS

Itasca developed a two-prong strategy for building strong relationships with regional K-12 students, teachers, and schools. The first prong was cultivating an overall student interest in the field of engineering through high school visits and hosting regional engineering events. The second prong was focused on developing personal connections with students from these high schools before they started their college academic careers. The connections built a trusting and cooperative relationship between students and their future college instructors. This created a foundation for student success that helped with the transition from high school to college and then continued, as the students progressed to their four-year transfer institutions and into their early careers.

3.2.2. DESIGN AND PROFESSIONALISM SPINE

Itasca developed a two-year engineering and professional development (EPD) course sequence to focus on developing the students as engineers and professionals. This course sequence focused on (Johnson and Ulseth, 2011):

- Student Development - Each semester students learned and practiced the skills needed for success in college and the profession. Example topics were time management, study methods, stress management, personal health, personal finance, and fitness. This component of the four-course EPD sequence was focused on increasing the level of student efficacy, which is positively related to student academic success and adjustment during the first year of college (Sheppard, et al., 2009).

- Engineering Development – Students practiced engineering in an increasing level of sophistication each semester. Students learned the project management and teamwork skills needed to successfully integrate their engineering knowledge into practical application.

- Professional Development – Students developed the professional skills of ethics, etiquette, interviewing, giving presentations, “dressing for success,” and interpersonal communication as an integral part of the EPD sequence. Program graduates refer frequently to the positive impact the professional development activities had on their experiences as interns and, ultimately, in their careers.

- Citizen Development – Students learned that, as engineers, their career role was one of being a servant to society. Students developed this identity through presentations, reading activities, and completing a minimum of 70 hours of community service. Examples of the activities included road-side cleanups, recreational trail maintenance, teaching science and engineering activities at local elementary schools, and volunteering at the local food-shelf, Habitat for Humanity, animal shelter, and homeless shelter. Through these experiences, a culture was fostered in which these future engineers developed as individuals that make an active difference in the communities in which they live.

This four-course EPD sequence provided students with the professional practice experience needed for preparing them as future engineers “who are both competent and attuned to the full range of demands and possibilities inherent in the professional practice of engineering” (Sheppard, et al., 2009).

3.2.3. ACTIVE FACULTY AND STUDENT LIFE

The Itasca learning community had a very active faculty *and* student life component with multiple activities focused on developing strong working relationships between faculty and students that enhanced the student learning in the classroom and improved student retention rates. The program had developed into a family of learners – students, faculty, and staff – which recreated together, socialized, learned, and interacted on a 24/7 basis. The elements of the program included many different student/staff/faculty sub-communities within the larger community (Johnson & Ulseth, 2011):

- "Approximately 100 engineering students lived in the engineering housing facilities. This living community incorporated weekly events and additional mentoring experiences. Pike, Schroeder, and Berry (1997) related persistence to success in residential learning communities.
- Several learning community events placed faculty and students together in a setting outside of the classroom. Events such as camping trips, basketball leagues, engineering Olympics, Itasca engineering triathlon, Pi(π) run, and hotdog roasts at faculty members' homes were key elements of the relationship building that made Itasca unique.
- The learning community supported interest in specific clubs with significant student and faculty participation: science café, outdoor adventure club, chess club, engineering modern dance club, engineering acting, curling club, a basketball league, etc.
- At any time during the year, there was a planned engineering learning community-wide event being executed. Examples included: Saran-wrap canoe contest, cribbage tournament, fishing contest, spaghetti feed, Yahtzee tournament, cross-country skiing, and much more.
- Several times per year, organized transfer trips were taken via motor coaches during which students and faculty visited the engineering programs at the regional engineering universities.
- There were multiple "plant-trips" per year that brought students to industry settings where they learned more about the different disciplines of engineering" (Johnson & Ulseth, 2011).

All of these activities built relationships and enhanced the quality of interaction between students and faculty. Braxton, et al., (1997) and Tinto (1998) "relate persistence to completion and quality of student-faculty interactions. The level of student-faculty interactions and the student connection to the engineering learning community at Itasca improved the quality of student learning and increased the level of student success in the completion of a four-year degree" (Johnson and Ulseth, 2011).

3.2.4. BLOCK SCHEDULING OF COURSES

For many engineering students who start at a community college or who are "second tier" students (Felder, 1993; Sheppard, et. al., 2009), the calculus math sequence is a key factor in their completing an engineering degree and influences the length of time to their graduation. This is due, in part, to the math prerequisites traditionally required for engineering and physics courses. In order to finish a bachelor's engineering degree in four years, a student must start Calculus 1 in the fall of the first year and then successfully complete all the required math and STEM courses on the very first attempt and in a specified order. If any of these conditions are not met, the students will face a one-semester or one-year delay in starting and/or completing their engineering education.

Itasca developed its block scheduling as one potential solution to provide more flexible academic pathways (Johnson, et al, 2011). Math, science, and engineering courses at Itasca were taught in eight-week block class format instead of the traditional 16-week semester format. Students generally took two engineering, math, or science classes per eight-week block, while completing one or two semester-long general education courses. Each block class is scheduled for two hours per day, five days a week with the flexibility for the instructor to provide a "float" or non-contact day each week for student work days or engineering program events. The format of two eight-week blocks per semester provided students with the opportunity to catch up to their "calculus 1 ready" peers in their STEM courses and stay on track to complete their degree in four years. A student could start the semester in Pre-Calculus, finish it in the first eight weeks, and then finish Calculus 1 in the last eight-week block of the semester. The model addressed a multitude of scenarios for math course sequences, which could cause a delay in the completion of an engineering degree in four years, such as a student's starting math course, performance in a particular course, and potential scheduling issues such as full courses.

In addition, the block schedule allowed students to pursue academic interests such as study abroad programs and co-op learning experiences, and come back to school and readily catch up to their peers. Each year, about 10% of Itasca's engineering students participated in a student exchange program with Svendborg Technical School in Denmark. Due to the block schedule, these students were able to participate in this eight-week study abroad program with no impact on their time to graduation.

3.2.5. ACTIVE LEARNING STRATEGIES

The flexible five-day, two-hour class format also enabled a better setting to create an active student-learning environment. The engineering program's math, chemistry, physics, and engineering faculty were dedicated to meeting Educating the Engineer 2020's call for engineering education to "address how students learn, as well as what they learn, in order to ensure that student learning outcomes focus on the performance characteristics needed in future engineers" (National Academy of Engineering, 2005). The faculty focused their efforts on studying and adapting the latest in the knowledge of engineering education. This led to further study and application of active student learning methods or problem- and project-centered learning, lab-centered instruction, modeling eliciting activities, academic journaling, etc. into the curriculum to help students attain the skills, experiences, and knowledge necessary for success in their engineering education and, ultimately, their engineering careers. An important step along the pathway toward project-based learning was Itasca's involvement in the EPICS program, founded at Purdue University. EPICS utilizes engineering design in the context of service learning in local community service (Coyle, Jamieson, & Oakes, 2005). The key components of EPICS design projects are service, academic content, partnerships/reciprocity, mutual learning, and reflection (Lima & Oakes, 2014). The ideals of EPICS aligned with the experiences desired in the EPD sequence. The focus on reflection turned a new page in our pedagogical approaches that would last deep into the development of the IRE model to the point that reflection became a core value of the program.

3.2.6. STRONG ARTICULATION AGREEMENTS WITH REGIONAL FOUR-YEAR INSTITUTIONS

Dimitriu and O'Connor (2004) identified that one of the elements vital to "recruiting and retaining students in a community college engineering program and preparing them to be successful after transfer to a four-year university" was to "increase coordination of curriculum between community colleges and four-year universities by obtaining articulation agreements with surrounding area institutions" (Dimitriu and O'Connor, 2004). Itasca had developed strong working relationships and articulation agreements with the several regional engineering programs. This led to the relationship that would evolve with Iron Range Engineering.

Figure 3.1 shows a mapping of these six curricular elements of the Itasca Community College engineering program.

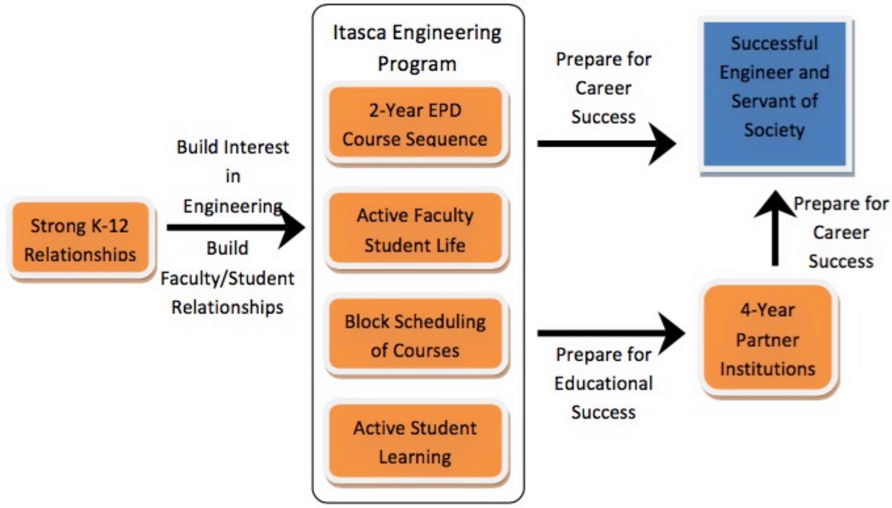

Figure 3.1. Elements of Itasca engineering program model (Johnson and Ulseth, 2011)

This model created a learning experience with a demonstrated level of success for the diverse body of second-tier students starting their learning in the community college pre-engineering program. At the time that Iron Range Engineering began to be developed, students were completing their engineering bachelor's degree in an average of 8.8 semesters with graduation rates of 49% for all students who start the program and 67% for students who start with or achieve a "calculus 1" math ability during their college education (Johnson and Ulseth, 2011). Itasca's 49% and 67% degree completion rates compared well with the degree completion rates of other institutions and studies (note that most students entering the comparison institutions would be starting with Calculus 1 as a first math course):

- 40.8% national engineering/engineering technologies degree completion rate from a U.S. Department of Education study (Chen, 2009).

- 69% six-year graduation rate for engineering students at Michigan Technological University, a transfer institution for Itasca students (M. Provoast, Associate Director of Admissions, Michigan Technological University, telephone interview, January 10, 2011).

- 56% six-year graduation rate for incoming fall 2001 engineering students at the University of North Dakota School of Engineering and Mines, a transfer institution for Itasca students (C. Osowski, Outreach Coordinator, University of North Dakota, School of Engineering and Mines, telephone interview, January 19, 2011).

- 45% male and 49% female graduation rates for incoming fall 1996 students in a 2005 study of the Southeastern University and College Coalition for Engineering Education (SUCCEED) Institutions (Borrego, Padilla, Zhang, Ohland, & Anderson, 2005). SUCCEED institutions award over 1/12 of all U.S. engineering degrees and includes Clemson University, Florida A&M University, Florida State University, Georgia Institute of Technology, North Carolina A&T State University, North Carolina State University, University of Florida, University of North Carolina at Charlotte, and the Virginia Polytechnic Institute and State University at the time of the study.

Despite this level of innovation and success in creating a learning experience that helped students in their academic success, there was always a frustration in the experiences that students had at their transfer institutions (Kreck, 2013). Despite the national and international calls for change in engineering education, the students were still receiving a very traditional model of education in the upper-division programs into which they were transferring. It is in this context that a small group of prime-movers at Itasca Community College began to dream about change and set an initial vision. It is at this point that the Iron Range Engineering chapter begins in the history of this engineering educational change.

3.3. ORGANIZATIONAL CHANGE MODEL

The history of the Iron Range Engineering program can be analyzed through each of the 8 steps of the organizational change model.

3.3.1. ESTABLISH NEED AND ENERGY FOR CURRICULAR CHANGE

The need for curricular change came from national and international calls for change in engineering education (Ulseth, Froyd, Litzinger, Ewert, & Johnson, 2011; Kreck, 2013; Ewert, Ulseth, Johnson, Wandler, & Lillesve, 2011), dissatisfaction by leadership team in national responses to the calls for change (Cole, 2012a; Ulseth & Johnson, 2014; Ulseth & Johnson, 2015), dissatisfaction with the student upper-division experience after they left Itasca Community College's lower-division program (Kreck, 2013), misalignment of the student learning experience with the intended graduate outcomes (Ulseth & Johnson, 2015), and a regional need for work-force and economic development (Cole, 2012b; Ulseth, Froyd, et al., 2011). A small group of prime-movers at Itasca Community College in Grand Rapids, Minnesota [insert map of MN] began to dream about change and set an initial vision. These prime-movers provided the energy for curricular change from the inception in 2003 (Cole, 2012a) through development and implementation to present day.

3.3.2. GATHER LEADERSHIP TEAM

The original direction came from the small group of Itasca Community College faculty members. This group sought outside guidance from a variety of sources in engineering education from across the U.S. through a small planning conference in 2003. From that planning conference emerged a group of five members that would steer the direction, develop and evolve the model and seek funding (Cole, 2012a) over the next five years. In April 2009, funding was approved for the initiation of the program (Ramsay, 2011; Office, 2009). At this point, the original members of the steering committee sought a highly regarded set of leaders from U.S. engineering education to guide and advise the program's development. This national advisory board included: Jeffrey Froyd (Texas A&M), Sheri Sheppard (Stanford), Tom Litzinger (Penn State), Denny Davis (Washington State), and Ed Jones (Iowa State).

In addition to the national advisory board, the program leaders quickly developed relationships and sought leadership from local industry, state legislators, the funding agency, university leaders, and local college leaders. Program partnerships are shown in Figure 3.2.

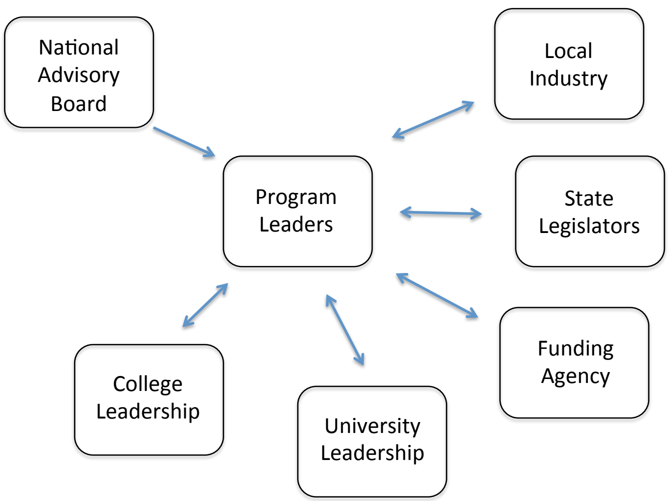

Figure 3.2. Program partnerships

3.3.3. NEW OBJECTIVES AND LEARNING ENVIRONMENT

The new advisory board provided much direction for the program leaders as the program developed with immediacy, as the curriculum would be delivered only 9 months after funding. The national advisory board developed the program's first set of program educational objectives (see Figure 3.3) and pointed the program leaders to Aalborg University. Program leaders visited Anette Kolmos in Aalborg in November 2009. This meeting and the Aalborg model provided the leaders a framework for project-based learning on which to attach the myriad of curricular ideas they brought forward from the six years of curricular innovations. The initial curriculum delivered in January 2010 was this adaptation of the Aalborg model (Ulseth & Johnson, 2015). The learning environment development took place over several years of evolution between 2009 and 2014.

The program educational objectives for Iron Range Engineering are listed below and have been published on the official IRE website. They are consistent with the Iron Range Engineering Program Mission to serve northern Minnesota. Graduates will achieve at least two of the following objectives, but will be capable of achieving all within one to four years of graduation:

1. Designing, implementing and integrating thermal, electrical, mechanical, and computer-controlled systems, components, and processes that will serve the region, the nation and the world.
2. Continuing their education through technical or professional graduate programs, professional licensure, or certifications, and the wide variety of other types of life-long learning.
3. Creating, developing, leading, and managing in a wide range of enterprises that result in sustainable and enhanced economic regional development through their disciplinary expertise.
4. Demonstrating actions such as community service, professional ethics, professional responsibility and mentoring future engineers.

Figure 3.3. Iron Range engineering program objectives

The learning environment from a physical sense was initially dictated by the space available for the program as tenants on the local college campus. Each year from 2009 to 2013, the available space changed and grew until, in 2013, a new facility, funded and designed specifically for the program, was opened (Ramsay, 2013). The important aspects for the physical learning environment were space for project teams to collaborate, space for learning conversations between students and academic staff, space for students to construct physical models and prototypes, and community gathering space. Through each evolution of the physical learning environment, the quantity and quality of these spaces increased.

The other qualities of the learning environment that were specifically developed, and then refined over time, were a highly collaborative nature among students, teams, and staff (Arendt, 2014), and a major emphasis on the development of professional responsibilities and skills, self-directed learning abilities, and design thinking.

3.3.4. DISCUSSION OF THE NEW OBJECTIVES AND ENVIRONMENT WITH THE COLLEGE AND REVISE BASED ON FEEDBACK

The program leaders were implementing a program that was a collaboration between a two-year community college and a four-year university (Arendt, 2014). The community college district was the fiscal owner of the program and provided the tenancy. The university owned the degree granting, the curriculum, and the majority of the teaching staff. The physical location of the program was 200+ miles from the university. There was a dichotomy in the relationships between the program and the collaborative institutions. The community college district gave the program great autonomy over fiscal decisions and environmental decisions; whereas, the university engineering departments and college were quite restrictive and frequently objected to much of the pedagogy and curriculum. Allendoerfer et al. (2015) thoroughly studied and documented this change process. The result of the situation was that the program leaders advanced the deployment of the curriculum through the PBL pedagogy using the objectives and outcomes from the national and industry advisory boards. The university ultimately approved the curriculum nearly two years after it was first implemented.

3.3.5. IMPLEMENT THE NEW CURRICULUM

In January 2010, the pilot curriculum began. The elements of the curriculum evolved almost daily. By the end of two semesters, it had taken a recognizable shape. In Appendix A, the authors describe the pilot curriculum at the end of one year of implementation. The first year pilot was characterized by industry-provided, ill-structured, project-based learning. The professional, design, and technical learning domains were integrated and focused on the project. Attributes of the learning environment included oral exams, deep learning activities (DLA), reflection, and metacognitive analysis. Further student evaluation was based on Bloom’s modified taxonomy (Ulseth et al., 2011).

3.3.6. EVALUATION

The Iron Range Engineering model of continuous improvement is thoroughly summarized in Chapter 4 of this thesis. The model provides for a periodic evaluation of internal and external input on the strengths and weaknesses. The evaluation is followed by the creation of new goals or modification of previous goals and the establishment of an action plan for the implementation of the goal (Bates & Ulseth, 2013). From the very first year, the program regularly invited visiting experts to spend time immersed in the model; observing student and staff learning activities and interviewing students, staff, and industry partners. While the number of external visits, by a wide variety of experts from across engineering education, numbered two – four per year, one group of external advisors visited regularly. They made four visits between 2010 and 2015. Their reports provided a longitudinal view of the evolution of the program. Their first visit, in early 2011, provides insight into the strengths and the weaknesses of the pilot implementation. The members of the visiting team across the time span were Rose Marra, University of Missouri (all four visits), Carolyn Plumb, Montana State University (three visits), David Jonassen, University of Missouri (deceased, one visit), and Betsy Palmer, Montana State University (deceased, one visit). The first report was submitted in April 2011 and serves to evaluate the pilot implementation of the IRE model (Jonassen, Marra, & Palmer, 2011). The series of reports is referred to by the program as the Marra-Plumb reports.

The external evaluation of the pilot model raised several issues that would need to be addressed in future evolutions of the model (Jonassen et al., 2011):

- Students and staff had an inadequate understanding of the purposes and uses of Bloom's taxonomy. The hierarchy associated with taxonomy was translated as a way to assign grades to students, putting a lower emphasis on areas within the taxonomy that were important for student development.
- Related to the taxonomy issue, evaluation of student learning was misaligned with the goals of student learning.
- Highlighted in the first evaluation, and continually addressed well into the program's development, was the connection between technical learning of competencies directly related to the project vs. competencies not related to the project (Marra & Plumb, 2012; Marra & Plumb, 2013). This stems from the curricular requirements for graduation (http://cset.mnsu.edu/ie/ire.html). By these requirements, students need 32 upper-division technical credits in their last four semesters for graduation. Of the 32, 16 are prescribed, and 16 are elective. In a given semester, a student completes eight technical credits. The first evaluation highlighted high levels of student motivation and interest in those of the eight that were most directly related to the semester project, and inadequate learning in the others. Over the next five years, program staff would attack this problem from a variety of ways until it was mostly mitigated by the 2015 Marra-Plumb evaluation (Marra & Plumb, 2015).

- Metacognition was identified as an important aspect of the IRE curriculum (Jonassen et al., 2011). Students were metacognitively reflecting on all aspects of their professional, design, and technical learning. However, students and staff were operating under a limited view of the concept. Recommendations were made to institute a metacognitive training program to "support the kinds of learning and problem solving required by IRE, including more work on task types, methods for assessing personal comprehensions and ability to solve different levels of learning, and application of alternative strategies that can be applied" (Jonassen et al., 2011). Here again, several years of development and continuous improvement brought the program to a higher level of operation: "we think that, for now, a very effective set of activities (immediate reflection, end-of-semester metacognition memo, and the Professional Development Plan) is in place, and no changes should be made" (Marra & Plumb, 2015).
- An essential element of PBL is students working in teams. The first evaluation highlighted issues with the program and its ability to support students working in teams. Two big issues were highlighted. First, was regarding students migrating to their own areas of expertise and thus not getting experiences in the areas where they most needed development. The second issue was that traditional gender roles were being assigned within teams. For example, women often were assigned roles relating to organization and communication, whereas men would be doing fabricating such as welding. The first issue was addressed through improved training of facilitators. The second issue ultimately resulted in the program hiring external consultation on gender diversity analysis and training. Several tools have been developed for IRE to use with students and staff on an ongoing basis to focus on inclusion (Bogue & Marra, 2015).
- Another element of the IRE model is the use of oral exams for all technical learning. This is unique in that the norm for technical learning is the use of written examination. It is an adaptation the developers made from the Aalborg model. Raised as an issue in the evaluation of the pilot implementation, was an inconsistency in the deployment and evaluation of oral exams by academic staff. During the pilot implementation, there were very few developed rubrics for any evaluation. The external evaluators noted this. They recommend rubric development for oral exams (Jonassen et al., 2011).

The pilot implementation was seen internally by staff and students and externally by visitors from engineering education as "particularly strong in helping students to develop lasting technical, design, and professional competencies associated with the industry based problems they [were] solving" (Jonassen et al., 2011). It was this sense, a sense that the vision dreamed of by the early leadership team had a good chance of being realized, that kept a high level of optimism in light of the obvious needs for improvement identified in the first Marra-Plumb report.

3.3.7. IMPLEMENTATION PLAN

The implementation team was guided forward at each juncture by the model for continuous improvement described in Section 4.5. As the pilot concluded, the future implementation plan resulted from a reaction to the external and internal inputs for improvement. Plans were made and implemented on a semester-by-semester basis. The program adopted an OAR (Observation, Action, Result) method to track changes. The implementation of the IRE model deviates slightly from the organizational change model in that the organizational change model is geared towards changing a larger college, where the results of the pilot would be converted to a plan for a larger implementation. At IRE, the continuing iterations of the model were all focused on the one program.

3.3.8. PREPARING FACULTY

The institutionalization of the approaches took place as the new semesters brought new groups of students and additional faculty members. New faculty and students were prepared to enter the model through orientation sessions at the beginning of the semester. Orientation workshops included new members of the community along with the returning members. Many details were provided on how the project, technical, and professional learning activities would be deployed. Each week, the learning community of students and staff would start with a two-hour seminar to provide grounding, connecting weekly activities to the overall goals of the program. Faculty met once each week for two hours to address how to meet students' needs across the three learning domains. These weekly sessions were how faculty were prepared for the new implementations and how new approaches were institutionalized into the model.

3.4. CURRICULAR AND ORGANIZATIONAL CHANGE

In Section 2.2, the two-layer model (de Graaff & Kolmos, 2007) is described. Viewing the history of Iron Range Engineering through the organizational change model in Section 3.3 and again from this two-layer perspective provides a more complete view of the model and its history.

3.4.1. CURRICULAR LAYER – STUDENTS

The funding of Iron Range Engineering as a new model of engineering education came from the Iron Range Resources and Rehabilitation Board, an agency of the state of Minnesota in April 2009 (Ramsay, 2013). The $1.2 million one-year budget came with the expectation that the program would deliver curriculum to students in the upcoming academic year. Program staff had not yet been hired, the national advisory board had not yet been formed, and the Aalborg model of PBL had not yet been identified. Starting the program in August 2009 was out of the question. There are two semesters in a college year in Minnesota. To meet the funding requirement of delivering curriculum and having enough time to organize and make decisions meant a start date of January 2010.

While one important aspect of implementing a new program is the curriculum, equally important is having a student body. The 2009 graduating class of Itasca Community College, students completing the first two years of their four-year bachelor's degree, were given the opportunity to join Iron Range Engineering as the first generation of students. 14 students stepped forward and took a leap of faith that their engineering education could be more valuable in a new model that was yet to be identified than it would be in one of the traditional engineering programs they would have otherwise entered. Figure 3.4 is a photo of the Generation 1 students.

Figure 3.4. IRE Generation 1 students

The students were hired as interns during fall semester 2009 to assist in program development. They started the curriculum in January 2010 and were the subjects of the pilot program. The IRE model of continuous improvement (see Figure 3.5) includes regular input from students. The Generation 1 students provided critical input throughout the entire 4 semesters of their education. They were exposed to rapid change and, as a result, had to acquire a skillset of flexibility and adaptability.

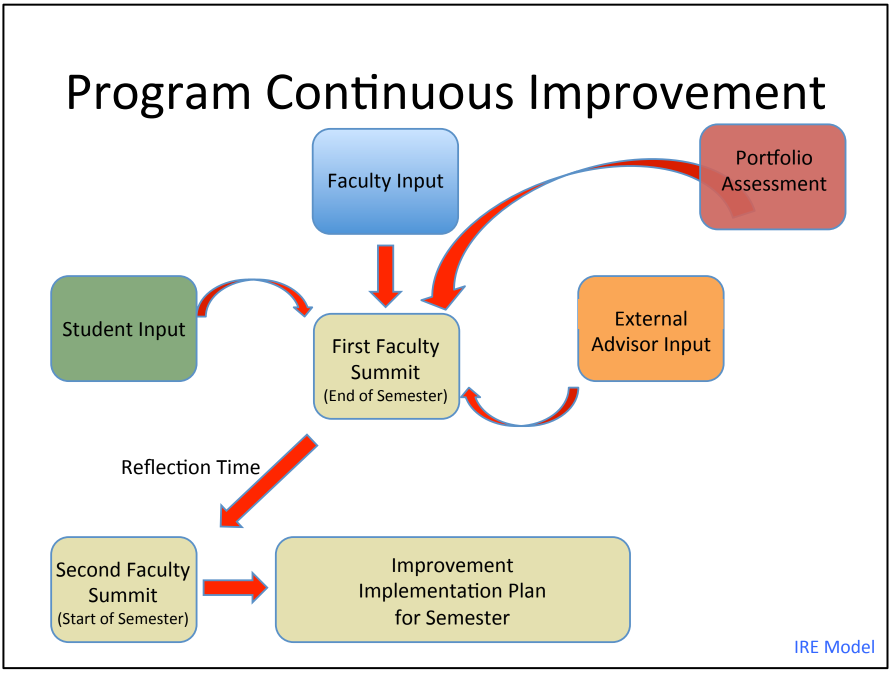

Figure 3.5. IRE continuous improvement model

All 14 students succeeded to graduation (Ramsay, 2011). The program is indebted to the group for their risk taking, trailblazing, and success (Ramsay, 2011). Figure 3.6 is a photo of the granite plaque permanently mounted to the wall in the Iron Range Engineering building.

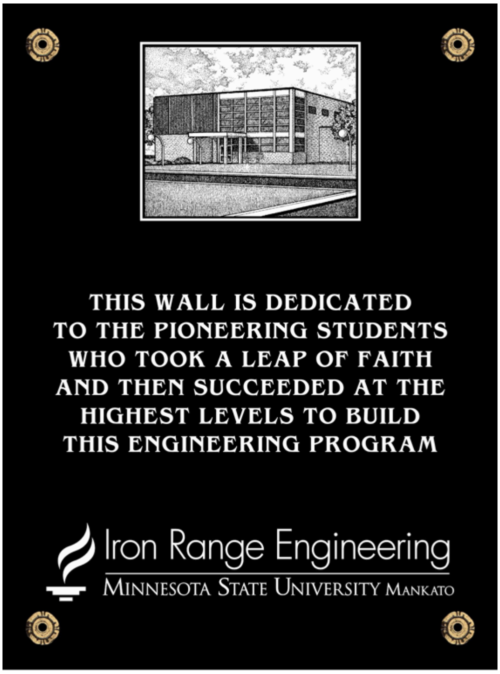

Figure 3.6. IRE plaque dedicated to early students

Attracting students to the program was hampered by the demographic conditions (low population) of the region, the new/unique/unproven nature of the program, and the fact that the program was not yet ABET accredited. However, each semester, new students enrolled. Table 3.1 shows the enrollments and graduates by the timeline.

Table 3.1. Iron Range Engineering enrollments

Semester	**Starting Generation (# of students)**	**Graduating Generation (# of students)**
Spring 2010	Gen 1 (14)	
Fall 2010	Gen 2 (10)	
Fall 2011	Gen 3 (23)	Gen 1 (14)
Spring 2012	Gen 4 (4)	Gen 2 (8)

Fall 2012	Gen 5 (8)	
Spring 2013	Gen 6 (16)	Gen 3 (20)
Fall 2013	Gen 7 (8)	Gen 4 (3)
Spring 2014	Gen 8 (13)	Gen 5 (7)
Fall 2014	Gen 9 (9)	Gen 6 (14)
Spring 2015	Gen 10 (10)	Gen 7 (8)
Fall 2015	Gen 11 (20)	Gen 8 (13)

The graduates were welcomed to industry for their new skillset. They achieved high levels of initial employment (Cole, 2012b). They have demonstrated high levels of satisfaction with the skills they brought to industry and their employers consistently rate them higher than their peers in performance (Ulseth & Johnson, 2015). The culture of the student body evolved over time from pioneering in the beginning to professional workplace in the present day. Currently, the culture is characterized as mature, thoughtful, and professional (Marra & Plumb, 2015).

3.4.2. CURRICULAR LAYER – FACULTY

During the first pilot semester, when there were 14 students, there were two faculty members, Dan Ewert, and Ron Ulseth. Ewert and Ulseth were engineering educators with more than 20 years of teaching experience each. They were members of the original team of dreamers from the early 2000's and were each highly motivated, by personal experience, to develop a new model of engineering education. Ewert had a background in electrical engineering and biomedical engineering. Ulseth had a background in mechanical and civil engineering. Both had industry experience, Ewert as the CEO of a startup company and Ulseth as a licensed professional engineer who practiced engineering in the U.S. Navy Reserve. Ewert and Ulseth served the program and the students in many roles. They directed the program externally by communicating with the advisory boards, funding agency, the colleges, and industry partners. Internally, they developed the curriculum and delivered it to students as the project facilitators, technical competency instructors, and advisors. There was one staff member in addition to the faculty members. He provided administrative support, coordinated student life, and assisted project teams access equipment and supplies. By the second semester, two new faculty members were added, a master's level electrical engineer and a retired practicing professional engineer. The electrical engineer provided technical expertise for students acquiring technical competence and facilitated a project team. The professional engineer served on an adjunct basis as a project facilitator. As time went on, the academic staff continued to have these components; full-time PhD engineers, master/bachelor-level engineers, and professional engineers from practice. Table 3.2 shows the evolution of the faculty over time. In addition to teaching faculty, the program has had non-teaching staff members provide crucial administrative support, technology support, laboratory management, and student life activity support.

Table 3.2. Iron Range Engineering academic staff

Year	PhD	Master's/Bachelor's Full-time	Professional Engineers Adjunct
2009	1	1	
2010	1	2	1
2011	2	2	1
2012	3	3	1
2013	3	3	1
2014	3	3	2
2015	3	3	3

While Ulseth and Ewert entered the academic staff with decades of engineering education experience, new instructors and facilitators were very new to engineering education, often joining the faculty to begin their career as educators. Ewert would leave the program after 2010. Ulseth remained to the time of PhD defense as the director of the program and a full-time instructor and facilitator. While not regularly on the ground as a full-time instructor, PhD student Bart Johnson played a role from the beginning. He served as an initial dreamer, an architect of the initial program, has served in the role as technical instructor of learning competencies, and 2013 - 2015 was the Chief Academic Officer at Itasca Community College and thus supervisor of the program's director.

The full-time faculty, from the beginning, served dual roles as technical instructors and project team facilitators. The nature of both the learning and instruction were different than the staff members had encountered in their prior experiences as either students or instructors. When a new member joined the faculty she or he knew they were coming to a PBL model where teaching and learning were different, and they were hired because of their desire to join the model. However, serving in the new roles required a paradigm shift. No longer were they expected to be an expert who possessed all of the knowledge and then transmitted to the students, but rather they became learning coaches and role models and team mentors. The acquisition of these abilities happened in real-time on the job. Each week from the program start in 2010, one or two hours were dedicated to faculty development of facilitation and instruction skills. In these sessions, faculty members discussed obstacles and successes they were encountering in their daily facilitation and instruction roles. They coached each other and strove for continuous improvement.

Evaluation issues regarding faculty were identified in the Marra-Plumb reports. Students were concerned about faculty being spread too thin (Marra & Plumb, 2012). The external evaluators were concerned about the faculty environment not being conducive to tenure (Marra & Plumb, 2013). Students and evaluators were concerned about the lack of consistency among instructors in how syllabi were implemented in technical learning (Jonassen et al., 2011; Marra & Plumb, 2012; Marra & Plumb, 2013; Marra & Plumb, 2015). As time went by, some of these faculty issues were resolved. For example: "Faculty are available in person, by phone, by e-mail – almost any time... Faculty are receptive to student feedback, and they respond to it" (Marra & Plumb, 2013). Other issues continued to persist, such as the consistency of faculty noted above in all four reports.

3.4.3. CURRICULAR LAYER – GOALS

The goals of the program at its inception can be seen in the poster in Figure 3.7. Ulseth and Johnson presented this poster at the ASEE Global Symposium in Singapore in 2010 in the midst of the pilot implementation of the model. Specifically, goals were (Ulseth & Johnson, 2010):

- Deliver new-look engineer with high levels of employability skills
- Student-centered curriculum and learning activities
- Industry-driven project-based learning
- Regional economic impact through engineering workforce development
- Integrated technical, professional, and design competencies
- High motivation, self-directed learning environments

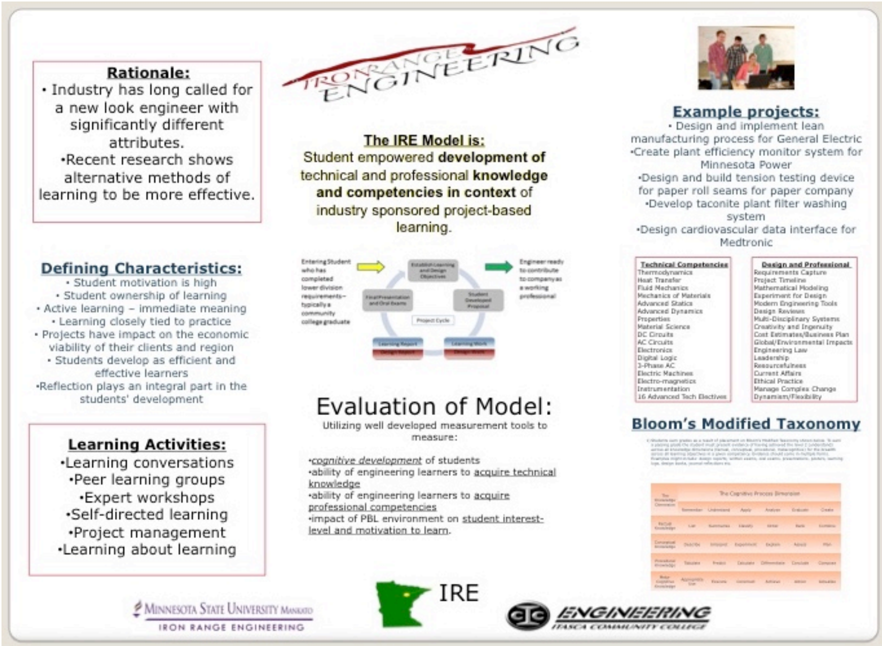

Figure 3.7. Poster Delivered in 2010 signifying the goals of Iron Range Engineering at program inception (Ulseth & Johnson, 2010)

The goals in 2010 are reflective of what the dreamers had in mind in the early 2000's (Cole, 2012a) and what was being delivered in 2015 (Lord, 2014).

3.4.4. CURRICULAR LAYER – SELECTION OF CONTENT

The program was conceived and designed to deliver a bachelor's degree in engineering so that graduates could enter the workforce. As an upper-division only program, the lower-division requirements were the same as any engineering student transferring to a traditional engineering program. Content selection thus was limited to upper-division programming. The three domains of content are described in detail in Chapter 3. They are design, professionalism, and technical competence. Figure 3.8 is a text box showing the description of the curriculum as it was designed, approved by the university curriculum process, and communicated to ABET in 2012 (Bates & Ulseth, 2012). Figure 3.9 is a graphical representation of the curricular content selected by the program (Bates & Ulseth, 2012).

The Iron Range Engineering B.S. in Engineering program is implemented each semester with a 15-credit load comprised of six courses of the types listed below:

1. Design (3 credits) – an industry-based engineering project addressed by a team of IRE students
2. Professionalism (3 credits) – independent study of core professional competencies that include learning and leadership, team work and communication, and professionalism and ethics
3. Seminar (1 credit) – exploration of contemporary engineering issues and wide variety of professional practice topics with external professionals and peers
4. Mechanical Core Competencies (e.g., 3 credits) – individual study of core ME competencies
5. Electrical Core Competencies (e.g., 3 credits) – individual study of core EE competencies
6. Advanced Engineering Competency (e.g., 2 credits) – individual study of advanced competencies related to design project and career interests

Figure 3.8. Curriculum Description (Bates & Ulseth, 2012)

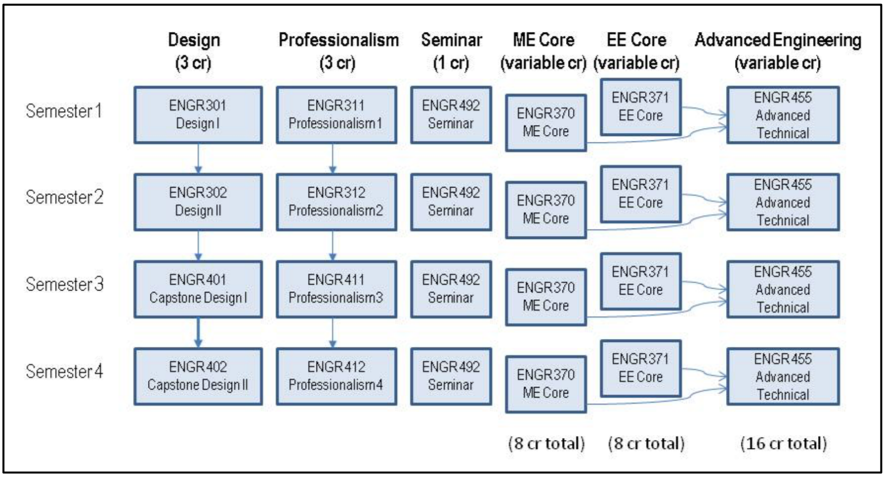

Figure 3.9. Graphical depiction of Iron Range Engineering content (Bates & Ulseth, 2012)

3.4.5. CURRICULAR LAYER – TEACHING AND LEARNING METHODS

The Aalborg Model of PBL served as the inspiration for the teaching and learning in the Iron Range Engineering program (Kreck, 2013). Central to the Aalborg model are project teams being facilitated by faculty project supervisors (Kofoed et al., 2004) in a dedicated group project space. The IRE developers adopted this model for the initial curriculum implementations in 2010. The project team, group room, project facilitator model remains unchanged and unmodified six years later, at the time of the publication of this thesis. Also adopted from the Aalborg model is the concept of process analysis, "The objective of process analysis is for the students to develop awareness of the work-and-learning processes, in order to become better project workers. Completion of the process analysis, which involves the student in documenting his/her reflections of the project process, has been a requirement in the (Aalborg) Basic Study Program since 1982" (Kofoed et al., 2004). The adaptation of process analysis at Iron Range Engineering extended beyond the project to the processes of personal, professional development through the PDP (professional development plan) and to technical competence learning through the metacognitive memos.

Departure from the Aalborg model came as developers looked to conceive a new model for technical competency teaching and learning. The original faculty members and students created the concept of the "Learning Conversation" during the pilot implementation. The philosophy behind learning conversations (see Section 4.4) was to have students access information between conversations and then bring questions to the discussion with their peers and teachers. Focus was put on conceptual understanding of fundamental concepts, in contrast to a focus on solving closed-ended problems using the fundamental concepts, as was prevalent in traditional engineering programs. The deliverable components of the technical competency were documentation of learning from personal learning and learning conversations, a deep-learning activity in which students used process learning to perform a "hands-on" activity, a metacognitive memo reflecting on the learning processes used and evaluating the effectiveness of the learning processes, and an oral examination focused on explaining the fundamental concepts and their application to the project.

3.4.6. CURRICULAR LAYER – ASSESSMENT

Curricular assessment in the Iron Range Engineering model happens at the program level and the individual level. The story of the IRE continuous improvement model for program level curricular assessment is described in Section 3.5 and alluded to in previous sections of this chapter. Student assessment, at the time of program implementation, was focused on the formative development of the individual in the technical, professional, and design project domains with the inclusion of team formative assessment in the design project domain.

Formative assessment took place within learning conversations as faculty members gave developmental feedback on the acquisition of knowledge of the fundamental engineering principles under study. Summative evaluation took place at the end of the technical competency as students were graded on the quality of their deliverables, which included documentation of technical knowledge gain, problem sets, deep learning activity reports, oral examinations, and metacognitive memos. As the program matured through the semesters and feedback came from the external evaluators, the importance of improving the quality of the formative feedback and being consistent in the summative evaluations was continuously highlighted and remains a need for the program at the time of this publication.

In the professional domain, the assessment was highly focused on formative feedback. The individuals were empowered to adopt a model of personal continuous improvement. In their first semester, students self-evaluated on a continuum of novice to expert their abilities and attributes in several professional development areas such as communication, leadership, teamwork, etc. Their project facilitators provided feedback to assist the students in calibration of their own impressions. At the end of each semester, the students reflected on growth and re-evaluated on the continuum giving evidence of the new assessment. Upon completion of the evaluation, they set goals for future improvement and developed action plans for implementation to move towards achievement of the goals. Again, students were given feedback by project facilitators. This cycle of personal, professional improvement continued through each of the four semesters of the students' education. The focus was on the formative growth though grades needed to be assigned at the completion of each semester. Students were given these summative evaluations based on the quality of their documentation of continuous improvement, rather than on an evaluation of how well the goals were met.

3.4.7. ORGANIZATIONAL LAYER – ORGANIZATION AND CULTURE

The culture at Iron Range Engineering has been characterized in the above sections. In this section, more attention will be given to the organizational structure and obstacles. IRE is a collaborative program. The two curricular partners are Itasca Community College and Minnesota State University, Mankato. The institutions are located 200 miles apart. A third collaborative partner, Mesabi Range College located 60 miles from Itasca and still 200 miles from Mankato, houses the Iron Range Engineering program. In a sense, the IRE program started as a "green-field" physically dislocated from the organizations and cultures that were its institutional "owners."

Allendoerfer studied the change process at IRE and presented the paper, "Leading a Large-Scale Change in an Engineering Program" (Allendoerfer et al., 2015), at the ASEE Annual Conference and Exposition in 2015. Her work highlights the tensions as the program was, in a way, resented by the engineering departments at the collaborative institutions for different reasons at each campus. The philosophical beginnings of the program were at Itasca. By leaving the Itasca campus, there was a feeling of loss, a feeling that the program belongs here, so why is it at Mesabi

Range? The reason for the location of the program on the third campus was one of funding. The leaders of the funding agency funded the program to reside at that location.

The feelings of resentment from Minnesota State University had two main roots. Whereas, at Itasca, the program was a bottom-up development, at Mankato there was very much a top-down "force-feeding" of the program from the university president to the engineering college in the short period described earlier in this chapter, from an idea being funded in April 2009 to its commencement in January 2010. The cause for resentment came from the PBL pedagogy. The department curricula and teaching and learning methods were being taught in the traditional method. The idea of PBL was seen as an affront to their way of delivering engineering education.

Allendoerfer interviewed all of the critical members involved in the startup of Iron Range Engineering. She interviewed the "dreamers" from Itasca, the faculty at Mankato, the IRE leaders, the politicians who funded IRE, the college and university deans, provosts, and presidents who were involved, and a consultant who negotiated the memorandum of agreement between the two institutions establishing the partnership. Figure 3.10, borrowed from Allendoerfer et. al. (2015) shows the organizational relationship at the startup of the program.

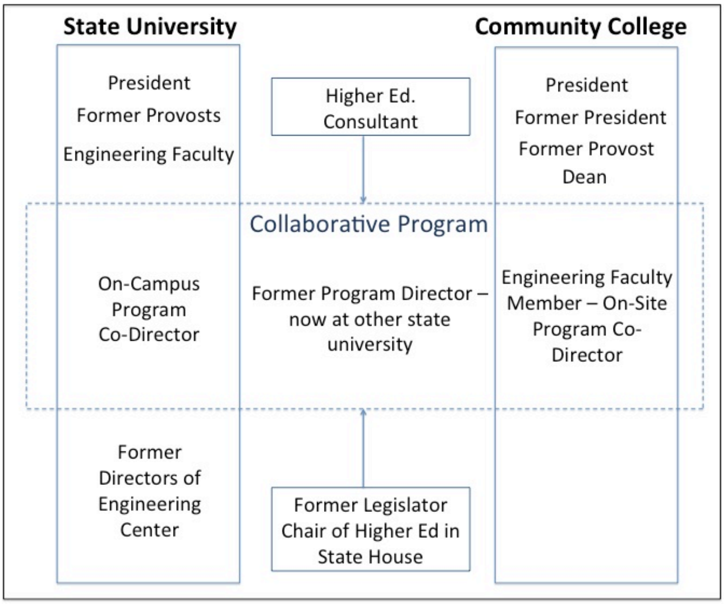

Figure 3.10. Organization and relationships at start-up of Iron Range Engineering. (Allendoerfer et al., 2015)

Identified in Allendoerfer's study were critical attributes of the change process and critical junctures in the process (Allendoerfer et al., 2015). An important event in the story of Iron Range Engineering occurred in early 2011. The program was into its third semester. Students on campus were on pace to graduate in December of that year. The PBL model at Iron Range Engineering was evolving on the trajectories described in earlier sections of this chapter. However, things on the Minnesota State University, Mankato campus were not going well. Ewert and Ulseth would travel to Mankato to try to get the degree and program courses approved by college and university curriculum committees. They were met with complete resistance.

> "I remember one time in a Curriculum Committee meeting we were going to explain, before we dropped the curriculum off on them, what the philosophy was. … Ulseth went to that meeting and I had him speak because they had known him. I was new, so I wanted him to [speak]. Well, then they saw him as being at Itasca Community College telling them how to educate engineers at a university. We're a community college; they're a university. Oh my gosh. One guy stood up and…yelled at us and he goes, 'This is just a ploy by community college to take over engineering education!' No." *Former Program Director – Ewert* (excerpt from Allendoerfer report)

In an attempt to end the impasse, the university president called a summit of leaders from the college, the university, and the program. The critical decision came when all parties agreed on putting in place a leader from Mankato's on-campus engineering college. The person selected was Dr. Rebecca Bates. Bates was able to understand the potential of the PBL pedagogy and understand the concerns in the college and work with both parties to find a path forward.

> *"The value is hiring the faculty there, but also having faculty back on the campus so the linkage, you know, in this case, and I think one of the reasons things went so well is because Becky was here. And people liked her. They knew her; they trusted her. She kept them informed on what was going on. And so long as we can continue with that, I think we're going to be fine. But if we ever get out of the loop from the main campus I think there could be some concerns." State University President* (excerpt from Allendoerfer report)

Bates was able to get the curriculum and degree approved. She has served the program as on-campus co-director ever since, acting as the liaison between the program and the university.

The summary of findings from Allendoerfer et al. (2015) includes the necessity of having champions at all levels, creating new organizational "boxes" or strategies to overcome obstacles, and identifying translators in key bridging positions (such as Bates). The works of Allendoerfer et al. have resulted in NSF funding to translate how these findings can be of value to other organizations looking to make similar curricular change.

3.4.8. ORGANIZATIONAL LAYER – VALUES AND CONCEPTUAL CHANGE

Iron Range Engineering exists more as an individual entity that emerged rather than as a part of an existing organization that underwent change. From this perspective, we analyze how the values of the program and its developmental trajectory emerge rather than how the values and developmental trajectory of an existing organization empower change within the organization.

The values emerged from the "dreamers'" desires to meet the international calls for change in engineering education. Those international calls are embodied in the National Academy of Engineering's Engineer 2020 (National Academy of Engineering, 2004). The attributes of the Engineer 2020 were not aligned with the learning activities undertaken by students in traditional engineering programs. The values of the Iron Range Engineering program emerged as developers sought to achieve that alignment. The alignment would come from students acquiring the professional employability skills needed to perform in their engineering careers, the ability to perform as self-directed technical learners, and from learning activities that aligned with the knowledge of how people learn. Restating, the values of the IRE program were to provide a learning environment where students could (Ulseth, Johnson, & Bates, 2011):

- Acquire professional employability skills
- Acquire self-directed learning abilities
- Learn, using techniques aligned with the emerging knowledge of how people learn

The conceptual change or developmental trajectory of the program emerged as an embodiment of the model of continuous improvement embraced by the program. Figure 3.5 shows how the program systematically evaluates itself each semester.

Described in previous sections, the model of continuous improvement extends beyond the program to the students in their development and the academic staff in their development. The program has a culture and a mindset of continuous improvement. This mindset defines the developmental trajectory of conceptual change.

3.4.9. ORGANIZATIONAL LAYER – PHYSICAL SPACE AND RESOURCES

The story of the acquisition of resources and physical space provide the last piece in the narrative of Iron Range Engineering through the perspectives of organizational and educational change. Kreck (2013) in Figure 3.11 and Cole (2012a) in Figure 3.12 detail the elements of how Iron Range Engineering got funding. The key player in the story was a passionate state representative in the Minnesota legislature, Tom Rukavina. He had dreamt for years about bringing engineering education at the bachelor's level to his rural district. See the story in the text box below.

Reprinted (with permission) from Education Commission of the States November 2013

"Iron Range Engineering – The third in a series of papers on rural education issues"
by Carol Kreck

Tom Rukavina, who now works for U.S. Representative Rick Nolan, was a Minnesota legislator for 26 years. "My district produced 60% of all the iron ore mined in Minnesota. Because of federal law, our land grant college, the University of Minnesota, received land and mineral rights. Just by chance, the land they received with the mineral rights contained iron ore. And over the last 100 years, the university has gotten millions of dollars from the mining companies that bought their ore," Rukavina told ECS.

Those millions went into a permanent fund as required by federal law with the interest going to research. This all happens in the Minneapolis/St. Paul area, and Rukavina worked for years to try and shift some of the money back to the Iron Range for higher education.

So Rukavina took a different path. "You see our mines pay a production tax in lieu of property taxes." The tax gets distributed to northeastern Minnesota schools, cities, and towns through a state economic development agency, the Iron Range Resources and Rehabilitation Board (IRRRB). "The production tax goes up each year … usually around 5 cents a ton of taconite, unless the legislature decides to freeze it."

In 2008, as house chair of higher education, he took that escalator and directed it to the IRRRB for higher education. At the time, with 40 million tons of taconite produced annually, that amounted to $2 million a year.

Also at the time, Rukavina met Ron Ulseth, a professor of engineering at Itaska (Itasca) Community College in the Range who had an idea for a new kind of engineering school, a purely hands-on program that would be based at a local community college. It was the kind of program that had been recommended in *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, published by the National Academy of Engineering, part of the National Academies, in 2005.

Figure 3.11. Education Commission of the States (Kreck 2013)

Thus, there was a regionally located, state agency capable of educational funding and a desire by some people to use this funding for engineering education. In parallel, the IRE group of dreamers were searching the country for funding opportunities to pilot their new ideas. In the text box below, Cole tells the story of how the two groups came together.

Reprinted (with permission) from Hometown Focus Newspaper April 27, 2012

"No One Does Engineering Like the Range"
by Jean Cole

"I started dreaming about how to do it better across the four years. I talked to people all around the country. I could envision a better way," Ulseth said. "For a couple of years, from 2005-2007, (We) tried to get funding, but there was no interest."

But Sertich (college president), Rep. Tom Rukavina of Virginia, and others were interested in somehow offering a four-year engineering program on the Range, and started exploring the possibilities in 2008. "I was skeptical," said Ulseth, "because I couldn't understand why anyone would choose to come here for the same old, same old."

By this time, Ulseth's son was a sophomore in high school and planning to become an engineer. "I didn't want to send him off for a 'hollow' experience," said Ulseth. "It was really bothering me." Then comes the "deer stand story."

"It was the last week of deer season: I was sitting in my stand. I was thinking to myself, 'Sertich wants this. Rukavina wants this. We have the same goal. We have different ideas how to get here, though. But then the light bulb came on. I thought I saw the way. I sent a text to Mike (Johnson, Provost of ICC). He was sitting in his deer stand, too. I told him, 'We can do it. Let's get everybody together for a meeting.'"

A meeting was set for the following Tuesday. "Monday night I sat down with some construction paper, it was red, I remember, and I made a Power Point presentation. This was November of 2008. After several more meetings, by (April) of 2009, we received funding from the IRRRB."

Figure 3.12. Hometown Focus April 2012 (Cole, 2012a)

Initiated in 2009 was a funding stream for Iron Range Engineering. It provided $1 million annually for staff, scholarships, operating expenses, and equipment and continues to do so to the present day (Iron Range Resources, 2010). This is an unusual funding pathway. Most funding in Minnesota public higher education comes in a direct allocation from the state. This is still public money but is money dedicated to the region in lieu of property tax income from the iron mining companies. This is how the educational change requirement for the organization was met.

The history of physical space follows a similar trajectory. In 2009, the program moved into a small section, in a corner of Mesabi Range College in Virginia, Minnesota. By the fall of 2010, as the Generation 2 students were starting, more space was needed. Again, the college provided space. During this timeframe, Representative Rukavina was seeking state capital bonding for a facility for the program. The bonding bill passed in 2010, only to be vetoed by the outgoing governor. In early 2011, in fact, on the day after the critical summit called by the university president to solve the collaboration stand-still (described previously), the new governor of Minnesota came to IRE to learn about the program. He was so impressed by the students and the model, he walked away claiming "your new building will be in my budget proposal by tomorrow." As the session ended, the governor and the legislature were at a standstill. The state government was shut down for several days. In the negotiations to end the shut-down, the governor passed a bonding bill that included a $3 million allocation to build learning space for Iron Range Engineering. In 2013, the facility opened with 10 new "group rooms" for project teams and major laboratory space for project manufacturing, modeling, and testing. The building has officially been named the "Tom Rukavina Engineering Center" (Bily, 2014), as pictured in Figure 3.13 at the dedication ceremony.

Figure 3.13. Dedication of the Tom Rukavina Engineering Center

3.5. SUMMARY OF IRE HISTORY

The history of Iron Range Engineering is a narrative that emerged from dissatisfaction with status quo and as a dream of a few for a new future of engineering learning. That dream of a few turned into the work of many (see Figure 3.14) who empowered the implementation of a new model of engineering learning.

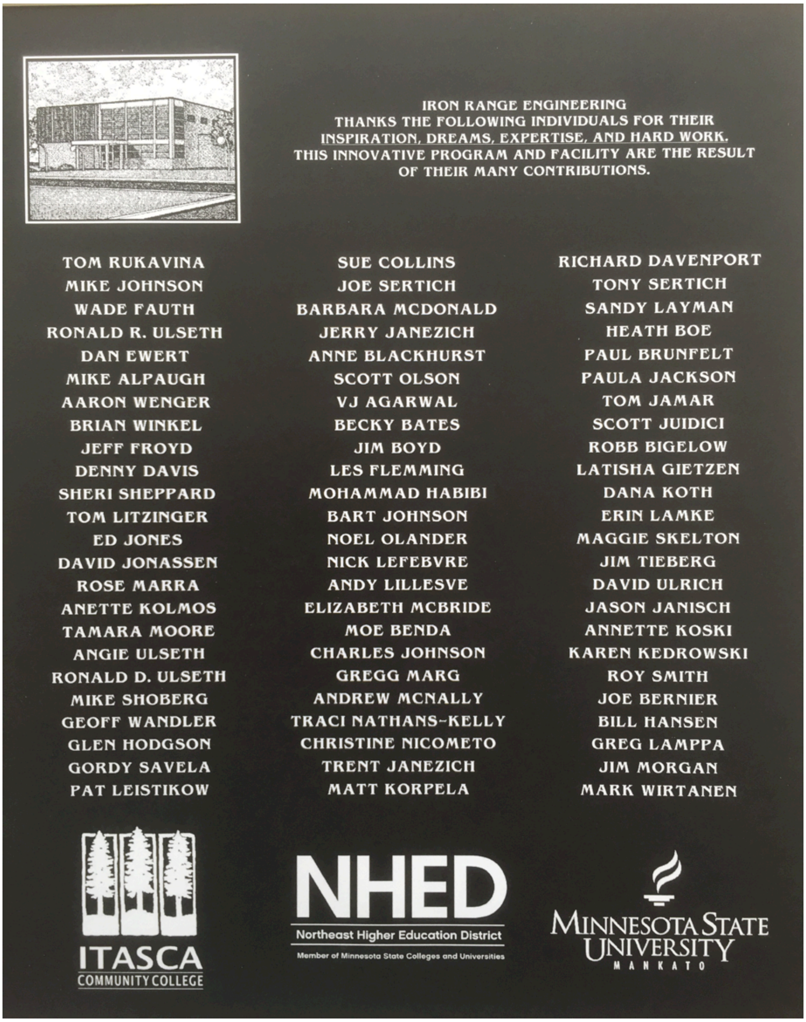

Figure 3.14. Granite plaque recognizing the contributions of many to the creation of to IRE

The underlying theme, repeated again and again, is one of continuous improvement. A mindset in which the successes of today are appreciated and the needs of today turn into a plan for improvement of tomorrow. The 2015 Marra-Plumb report highlights the story of IRE through its successes (Figure 3.15) of the present day and the needs for improvement (Figure 3.16) for the future. See text boxes below, (Marra & Plumb, 2015).

Highlighted Program Strengths in May 2015, (Marra & Plumb, 2015).

"Here are some observations about the many positive aspects we observed and that were reported:

- Nearly all students commented that they are learning more about "professionalism" than they would in a traditional program—and they appreciate that.
- During previous visits, we sometimes heard about concerns from students regarding how prepared they would be technically. Students, once they are in the program, do not seem to have that concern now.
- The program appears to have achieved an appropriate balance between structure and providing needed supports for students.
    - This is particularly true in the area of metacognition where you have adjusted the requirements for metacognitive memos without apparently diminishing the impact of metacognitive development.
    - Describe sheets used for preparing for Learning Conversations are also well received, as well as the first-semester seminar.
- In contrast to past visits, it appears the active Gens of students had realistic expectations of IRE on their arrival. They appear, overall, to be satisfied with the level of structure versus self-directedness.
- Assessment of learning, both oral and written, appears to be perceived as consistent by students; this is a definite positive change from past visits.
- Faculty are quite available in person, by phone, by e-mail—almost anytime.
- Most students voiced positive feedback about the group forming process—putting new students into a group with "experienced" students and, in some cases, letting students choose their own groups.
- Many students continue to perceive that what they are learning is "sticking" better than learning in a more traditional program.
- There has been a marked improvement in lab training and lab management procedures (see section below), which appears to have resulted in labs being a more comfortable and accessible environment for all.
- The Professional Development Plan seems to have strong support from students.
- Students report that the climate is collaborative rather than competitive—there is a sense of community

- A lot of learning continues to happen among peers.
- The program continues to have good relationships with industry partners."

Figure 3.15. Successes from Marra Plumb report

Highlighted Program Needs for Improvement in May 2015 (Marra & Plumb, 2015)

Recommendations: Learning Conversations

- Provide at least some faculty with more structure to be successful in their Learning Conversation implementations— for instance help in forming list of topics and a proposed schedule that is published to students.
- Have faculty discussions to help standardize the enrollment size of Learning Conversations. Some students reported that larger groups > 6 or 8 made it difficult for the Learning Conversation to actually be a "conversation." We note that more experienced faculty may have the ability to effectively keep a conversation "feel" even for larger groups.
- Implement a systematic mechanism for student anonymous feedback regarding the instructor, and formative feedback during the Learning Conversation eight-week period. (see tool being developed by Bogue and Marra) and use this feedback to make mid-Learning Conversation adjustments.
- Create standards that are adhered to for Learning Conversation syllabi. As one student commented: "Sometimes, with some faculty, it starts ok, then it unravels. Loses its structure. They need more planning up front. They know what needs to be taught, but not necessarily how they are going to teach it—or in what order. The presentation is not structured enough. Some faculty go too deep into first outcomes, then give short shrift to later outcomes. Faculty need to keep more on schedule."
- Strive for consistent expectations (across faculty) in Learning Conversations.
- Continue to work on both instructor and student understandings and implementations of "student directed." Although instructors should be encouraging student participation, they should not allow students to monopolize or derail the progress of other students.

Recommendations: Metacognition

- The program has had some changes in instructors the last couple of years. The level of understanding of the theory and research about metacognition amongst instructors may not be clear, and / or consistent. It might be valuable for faculty to have a more thorough understanding of metacognition: declarative vs. procedural, control vs. monitoring, etc. This might be addressed in a "faculty circle" periodically.

Recommendations: Student expectations

- Consider taking proactive steps to counteract some of the negative buzz prospective and current students hear; IRE is too new; you won't get a job; you won't learn enough technical content; IRE is only for mining or if you want to stay in the range.
- Students who are not focusing on EE / ME are sometimes still struggling to put together meaningful programs and finding expertise. Perhaps find such students – e.g. "environmental," a professional mentor, one who could help guide such a student; almost serve as a PBL facilitator for that student as he or she works through competencies that are not in expertise area of IRE faculty. Might need to pay such a person.

Figure 3.16. Needs for improvement from Marra Plumb report

3.6. ANALYSIS OF THE CHANGE

The history of Iron Range Engineering has been viewed through the perspectives of organizational change and management of educational change. The IRE model is one of both bottom-up and top-down change. Bottom-up in its creation as a new entity in northeastern Minnesota and top-down in its creation as a department in the College of Science Engineering and Technology at Minnesota State University, Mankato. The success of the start-up is evidenced by the continued existence and current vibrancy of the program. Section 2.1 of this thesis identifies and describes essential attributes for change to succeed. Table 3.3 below connects the essential attributes and how those attributes emerged in the IRE story.

Table 3.3. Connecting elements of change to Iron Range Engineering history

Essential Element of Change	Iron Range Engineering
Need for both external and internal drivers	-External: legislature, governor, funding agency -Internal: university and college leadership, program leaders
Leadership team	Ewert, Ulseth, Bates
Vision casting	-Alignment of engineering education

	activities with skills needed in profession -Regional workforce development -Alignment of learning activities with learning science
Empowering people to act	-University and college leaders empowered the program leaders to design and implement the program -Program empowered faculty and students to learn and succeed
Formative evaluation	IRE model and culture of continuous improvement

Key Finding: ***The analysis of the change and the identification of these elements for the IRE change add to the knowledge of change in engineering education. These elements are critical to the change accomplished and can be used in consideration of change within other engineering programs in the U.S. and add to the knowledge of change in engineering education.***

3.7. CONCLUSION

The purpose of this section was to describe and analyze the Iron Range Engineering program. The historical context provided in this chapter aims serves to establish why did the Iron Range Engineering program start and the Iron Range Engineering program evolved. The people who lived it wrote this history. They bring biases impacted by years of investment and experiences to these descriptions. In an effort to mitigate these biases, published accounts of the history are referenced frequently throughout. This chapter should be viewed as the historical analysis of the Iron Range Engineering program as experienced by the program developers and implementers. A counter perspective could be written as a result of a case study done by an impartial observer. Both perspectives could then be of value to those wishing to learn from the history of the program.

This Iron Range Engineering narrative is a set of accounts. It is an account of continuous improvement; it is an account of educational change; and it is an account of people, their dreams, and their willingness to take risks and persist. PBL is a social construct. It is embedded in the people and the place of its existence. The authors are often confronted with the question: “is this model transportable?” The answer is no. It is a function of its people, its time, and its place. However, by describing all of the theories, components, and contexts, a knowledge base for others to contemplate is provided. Just as was done by the developers of Iron

Range Engineering when they visited Aalborg University in 2009, curricular decision makers in other contexts can review, adopt and adapt the aspects of the IRE model that do fit in their program.

A better question is what curricular components of the IRE program can be transferred and adapted to different social settings, as occurred in the adaptation of element of the Aalborg model in the development of IRE. The next chapter will evaluate the PBL curriculum and it's curricular elements that can be considered, evaluated, and adapted to other education settings.

CHAPTER 4. NEW PBL CURRICULUM

(BART JOHNSON AND RON ULSETH)

The 2011 study of curriculum change by the Royal Academy of Engineering (Graham, 2012a) identified that successful change processes involve the entire curriculum structure being developed with the curriculum goals in mind. The structure must be interconnected and coherently support the change being made.

In this chapter, the program curricular structure will be described and analyzed two different ways. First with the seven curricular elements of the PBL curriculum model identified by (Kolmos, de Graaff, & Du, 2009), shown in Figure 2.14:

- objectives and outcomes,
- types of problems and projects,
- students' learning,
- progression and size,
- academic staff and facilitation,
- space and organization, and,
- assessment and evaluation (Kolmos et al., 2014)

Each element will be used to provide a brief analysis using the spectrum developed in Chapter 3. The spectrum for each element begins on the *discipline and teacher-controlled approach* on one end and then transitions to the *innovative and learner-centered approach* on the other end. The IRE PBL model will be analyzed by identifying its placement on each curricular element spectrum. Upon placement on each spectrum, the characteristics of the IRE PBL model for that element will be described in detail to create a robust description. The elements will be connected to the learning theory from Section 2.3, as appropriate.

Upon analyzing the model through the PBL elements in Sections 4.1 through 4.7, the analysis will continue, in Section 4.9 through classifying it with the theoretical approaches from Chapter 2. The chapter will conclude with the defining characteristics of the IRE PBL curriculum to create a concise description of the curricular model.

4.1. PROGRAM OBJECTIVES AND OUTCOMES

The program objective and outcome element spectrum has the *discipline and teacher-controlled approach* on one end; it is expressed by the learning objectives being very specific to the discipline itself. The knowledge content is, also, focused solely on that content that is pertaining to only the discipline itself (Kolmos et al., 2014). In contrast, at the other end of the spectrum, is the *innovative and learner-centered approach*; it focuses on interdisciplinary knowledge and methodological approaches associated with PBL (Christensen et al., 2006).

Placement on Spectrum

In the development of the IRE model, a choice was made to select learning outcomes that reflected the outcomes from the calls for change in engineering education (see Chapter 1.3). The IRE learning outcomes focus on three interdisciplinary domains of learning: technical, design, and professional. These outcomes are communicated to students as the three domains of being an engineer. This focus places the IRE model at the *innovative and learner-centered approach* end of the objective and outcomes spectrum, Figure 4.1.

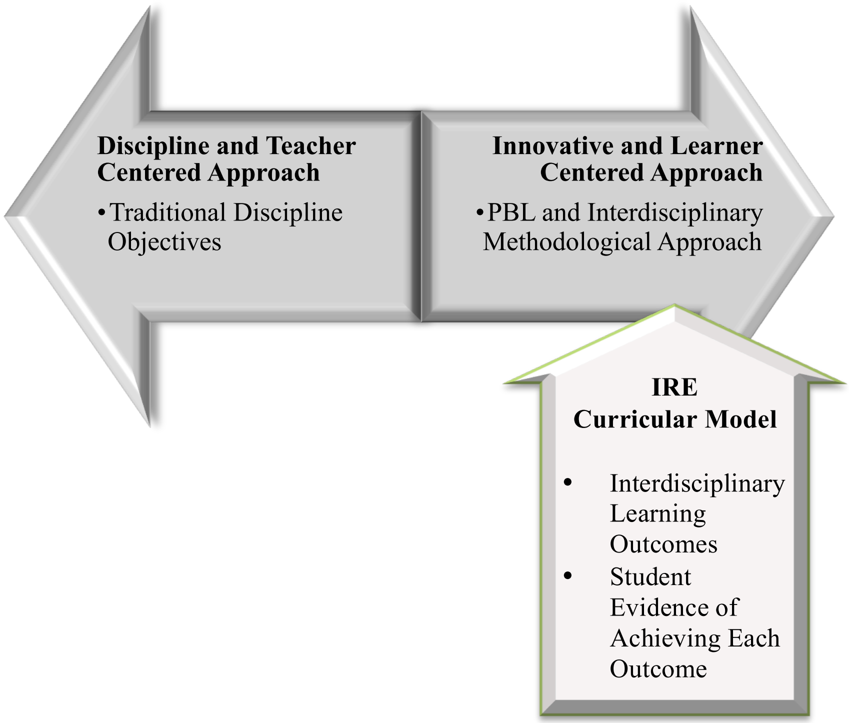

Figure 4.1. Objectives and outcomes spectrum

Characteristics of IRE Model

A program goal is to have all students achieve a desired level for each of the 14 specific learning outcomes within the three learning domains of technical, design, and professional. The IRE program is ABET-EAC accredited. As such, eleven of the outcomes are dictated by ABET. These are commonly referred to as the ABET a-k student outcomes (Abet.org, 2015). Based upon the economic development needs of the region and the recommendations of the two advisory boards, Iron Range faculty chose to add three additional outcomes: leadership/management, entrepreneurialism, and performing in inclusive environments.

Table 4.1 shows the IRE student outcomes. Appendix B includes the performance indicators (PI) that further define each outcome. It is through meeting the PIs that a student successfully meets an outcome. While ABET identifies the outcome, the individual program develops its own performance indicators. Programs achieve autonomy through the differing performance indicators.

Table 4.1. Graduate student outcomes

Technical Outcomes	Design Outcomes	Professional Outcomes
Technical 1. *An ability to apply knowledge of mathematics, science, and engineering*	Design 1. *An ability to design a system, component, or process to meet desired needs within realistic constraints*	Professional 1. *An understanding of professional and ethical responsibility*
Technical 2. *An ability to design and conduct experiments, as well as to analyze and interpret data*	Design 2. *An ability to function on multidisciplinary teams.*	Professional 2. *An ability to communicate effectively*
Technical 3. *An ability to identify, formulate, and solve engineering problems*	Design 3. *An ability to lead, manage people and projects*	Professional 3. *An ability to work successfully in a diverse environment*
Technical 4. *A recognition of the need for, and an ability to engage in life-long learning*	Design 4. *An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice*	Professional 4. *A knowledge of contemporary issue*
Technical 5. *An ability to engage in entrepreneurial activities* .	Design 5. *The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*	

The IRE outcomes and performance indicators are made explicit to each entering student as part of the orientation process. Each outcome has a rubric that describes levels of performance ranging from 1 (deficient) to 2 (weak) to 3 (acceptable) to 4 (desired) to 5 (exemplary). Table 4.2 contains an example rubric.

Table 4.2. Rubric for technical outcome 1

		Performance Levels				
Outcome Definition	Performance Indicator	1 = Deficient	2 = Weak	3 = Acceptable	4 = Desired	5 = Exemplary
An ability to apply knowledge of mathematics, science, and engineering	Verbally describe science, engineering, and mathematical concepts in an oral exam	Does not identify key concepts even with much prompting, or explanations reveal serious misconceptions	Incompletely identifies key concepts with much prompting or explains them inadequately for proper understanding	Correctly identifies key concepts with minor prompting and reasonably describes them both verbally and symbolically	Correctly identifies key concepts without prompting and explains them well both verbally and symbolically	Promptly identifies key concepts and explains them contextually with skillful use of language and symbols
	Apply science, engineering, and mathematical knowledge to solve closed-ended problems	Selects unsuitable equations or applies them incorrectly, yielding erroneous solutions to simple STEM problems	Selects and applies equations that are often unsuitable or inaccurate, produces questionable solutions to text-book-type STEM problems	Properly selects and applies equations, produces and presents correct solutions to text-book-type STEM problems	Accurately and knowledgeably selects and applies equations, correctly produces and presents accurate solutions to typical STEM problems	Skillfully selects and applies equations, adeptly produces accurate solutions, insightfully explains results to typical and novel STEM problems
	Use science, engineering, and mathematical knowledge in a deep learning activity	Does not document problem solving thought processes or documents poor thinking, problem solving, or learning achievements	Sparsely documents thought processes or documents dubious problem definition, expected outcomes, solution process, results obtained, or learning achieved	Acceptably documents reasonable thought processes for problem definition, expected outcomes, solution process, results obtained, and learning achieved	Fully documents sound thought processes for problem definition, expected outcomes, solution process, results obtained, and learning achieved	Skillfully documents exemplary thought processes for high quality problem definition, expected outcomes, solution process, results and learning achieved

The outcomes serve as the guidepost for learning. At the beginning of each semester for design and professional learning and at the beginning of each technical course, academic staff presents students with a syllabus stating course expectations. Explicit in these expectations are the learning goals for the course stated in terms of students meeting the outcomes. Students are graded in their courses using the outcomes rubrics to identify levels of performance. Throughout the two years of the PBL program, students accumulate evidence that they have met each performance indicator for each outcome. By graduation, they submit a portfolio with accumulated evidence, including a reflection where they verbalize how their work demonstrates the appropriate outcome achievement.

4.1.1. CONNECTING LEARNING OUTCOMES TO LEARNING THEORY AND RELEVANT COMPONENTS

Previously described in Section 2.3 were constructivism, Illeris' model, and the American Psychological Association's (APA) learner-centered psychological principles. The relevant components of learning environments discussed were: development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity.

The graduate student outcomes describe what the student should be capable of doing at graduation, but do not describe how the student should acquire the capability to achieve the outcome. Therefore, little from the outcome statements can be directly attributed to the learning theory and learning environment components.

However, the performance indicators listed under each outcome show how students can demonstrate outcome achievement. It is in these performance indicators that relationships can be made to theory and learning environment components. The sum of the outcomes and performance indicators draw balance towards the center of Illeris' triangle. For example (see Figure 4.2 below), in technical outcome 1, an ability to apply knowledge of mathematics, science, and engineering, the PI to "solve closed-ended problems", would be in the upper left vertex of content and cognition; whereas, the PI to "describe concepts in an oral exam" moves down the triangle as it takes place in an external interaction with others in the learning environment. Movement away from content also comes in the last PI, "use knowledge in a deep learning activity", where movement is toward the upper right vertex, providing incentive and motivation to use the learning in an application of importance to the learner. A similar balance is drawn towards the center by the PIs in most of the other outcomes.

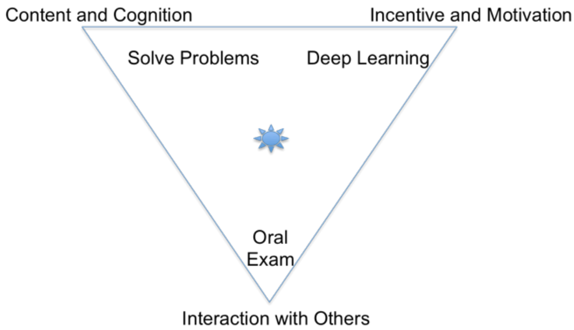

Figure 4.2. Placement of outcome on Illeris' triangle

Many of the performance indicators are constructivist in nature. To demonstrate the ability requires the student to construct her or his own knowledge; and the construction is impacted by the individual's past experiences while happening over time in a spiral type model. Example of PIs that meet this are "designing an experiment to answer a question related to technical work", "determine the reasonableness of a the solution to an open-ended problem", "critically judge design solution effectiveness based on project requirements", "evaluate quality of teamwork achieved", "apply metacognitive techniques to improve individual learning", and "write PDP goals that show interacting with others in a professional and respectful manner, in all situations, is a critical tool for success."

The 14 learner-centered goals, sequentially numbered, are listed and described in Section 2.3. Strong connections can be made between the APA learner-centered principles (APA, 1997) and IRE outcomes and PIs. Table 4.3 lists several strong connections.

Table 4.3. Connections between outcomes and APA learner-centered psychological principles

IRE Outcome	Learner-Centered Principle
Technical 1	7, 8, 9, 11
Technical 2	1, 2, 3
Technical 3	8, 9
Technical 4	2, 3, 4, 5
Technical 5	
Design 1	4
Design 2	10, 11
Design 3	12, 13, 14
Design 4	6
Design 5	6, 13
Professional 1	2, 11, 13
Professional 2	11
Professional 3	10, 13
Professional 4	11

The learning environment components directly addressed by the outcomes are the following: *reflection and metacognition* as they are required by the PIs in technical outcome 4 requiring learning journal reflections and use of metacognition; *motivation* as it is built by the contextuality of the design outcomes; *situativity* and learning community in design outcome 3, regarding team interactions; and *identity* as it is built in the elaboration of the professional development plans in professional outcome 1.

The learning outcomes of the IRE model are directly supported by the other curricular elements. Of greatest significance, is the type of project and how the design process and learning experiences support the student development of the learning outcomes, as demonstrated by their growth in the performance indicators.

4.2. TYPES OF PROBLEMS, PROJECTS, AND LECTURES

The heart of any project-learning program is the projects and how they interact with the lecture part of the student learning experience. For the curricular element of types of problems, projects, and lectures, there are closed-ended problems at the *discipline and teacher-controlled approach* end of the spectrum, which are identified with the traditional specific steps to a solution and a specific answer. At the i*nnovative and learner-centered* end of the spectrum, projects are ill-defined which leaves both the approach and the final solution to be determined by the teams and the students. These types of projects support the interdisciplinary approach of PBL.

Lecturing is part of the whole spectrum for this curricular element; however, its focus, content, and duration adjust based upon the type of problem and project work students are doing. In the *discipline and teacher-controlled approach,* lectures focus on knowledge transfer from the expert to the student. In the *innovative and learner-centered approach,* the lectures support the project. The emphasis shifts from knowledge-transfer to guiding students through the knowledge acquisition process as directed by their project work.

<u>Placement on Spectrum</u>

The development of the IRE model is characterized by the use of industry-sponsored projects with well-defined project scopes and open-ended solutions. The learning activities, or the "lecture component", of the curriculum are a purposefully integrated part of the project work and learning experience for the students. See Figure 4.3. This places the IRE model towards the *innovative and learner-centered approach* end of the objective and outcomes spectrum.

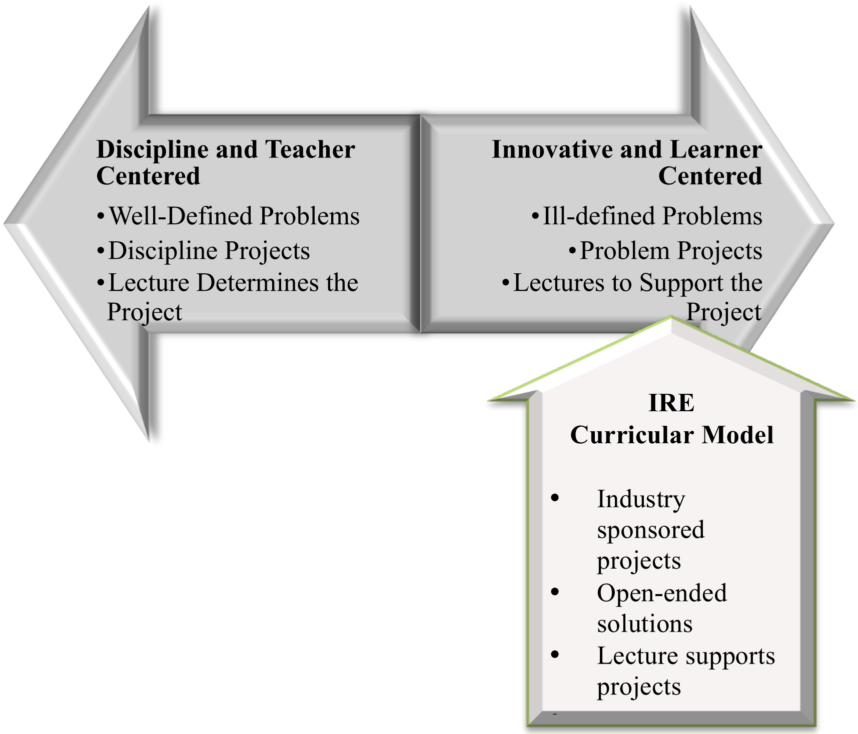

Figure 4.3. Types of problems, projects, and lectures spectrum

Characteristics of IRE Model

The project cycle in the IRE program lasts one academic semester. During the semester, one team, with the guidance of a project facilitator, completes a project for a client. The client is normally an industry partner; however, students can choose to do an entrepreneurial project in which they are their own client, inventing their own product or process. The industrial projects are real needs the company has for engineering solutions. The intent is for the companies to implement the student solutions. This often happens.

The process starts prior to the semester when students are queried about their interests in project types for the upcoming semester. Potential interest areas include, but are not limited to these: industrial mining, industrial other, manufacturing, consulting, biomedical, or entrepreneurial. Based on the results of this survey, the academic staff sends out a call for proposals to the program's current and potential industrial partners. Appendix C contains a sample project solicitation form. Students interested in an entrepreneurial project complete the same form. Once the industry partners and entrepreneurial students have submitted complete solicitation forms, the forms are compiled into one document that is deemed the "projects menu." The projects menu is distributed to all students. Students then select their top three choices. Academic staff compiles all of the student desires and create teams. Other considerations that staff use when assembling teams include prior student experiences and student personalities. The intent is to create a vertically integrated team with students from different semesters of the program and with different skill sets and development needs. Once a team has been assigned to a project, a project facilitator from the academic staff is selected for the team. Prior to the first day of the semester, the project facilitator will have met with the client to get a clearer understanding of the project scope.

The projects serve as the backbone for the student learning of the design, technical, and professional outcomes. The projects are selected to support the student competency development process such that they are able to demonstrate all 14 competencies by the time of graduation. The development of the student design outcomes will be described in the next section. The technical and professional outcome development will be described in Section 4.4, students' learning curricular element.

4.3. PROGRESSION, SIZE, AND DURATION

A defining characteristic of the progression of PBL is the percentage of time committed to project work or the extent of the project work within the curriculum. It is relegated to a minor part in the *discipline and teacher-controlled approach.* It could be an add-on to one or more courses and serve as a capstone senior design project.

In the *innovative and learner-centered approach*, the projects consume more and more time within the curriculum. As the time dedicated to projects increases, so does the impact the project work has on student learning. The learning outcomes that can be achieved in the PBL curriculum are dependent on this time commitment, as the learning takes time within the project teamwork.

Placement on Spectrum

In the development of the IRE program, a choice was made to focus on the 14 outcomes and for the students to develop depth in knowledge of each. This is in contrast to the breadth of discipline-specific topics pursued by most traditional programs. Within this PBL process, students are trained and developed in their ability to be self-directed learners. The intent is that students are deeper design, technical, and professional learners who have the ability to learn additional competencies in these three domains to support their careers in industry. This characterizes the IRE model as *innovative and learner-centered* as shown in Figure 4.4.

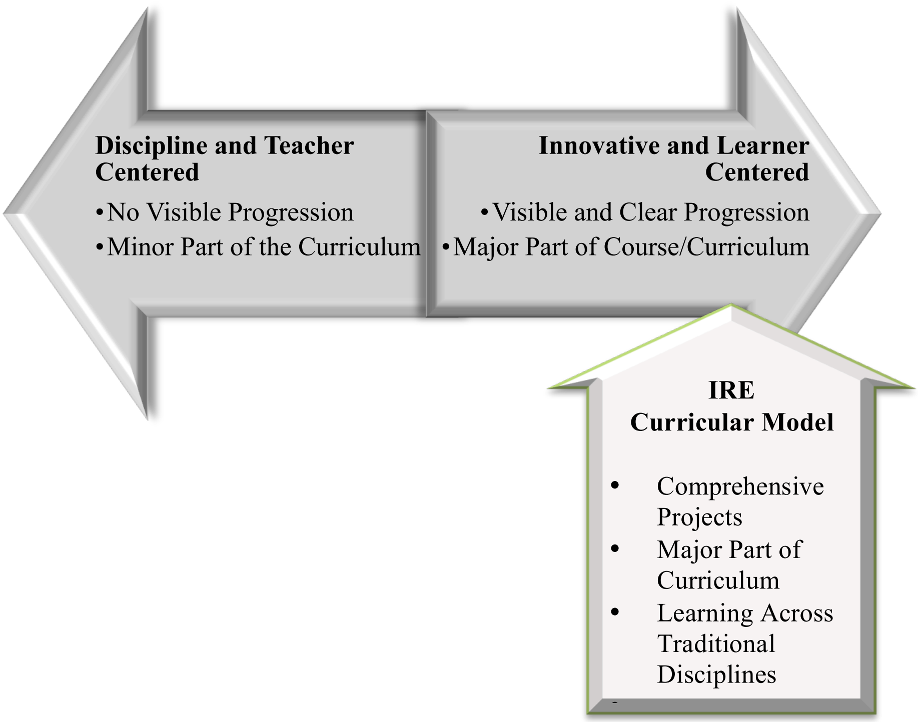

Figure 4.4. Progression, size, and duration spectrum

Characteristics of IRE Model

From the Savin-Baden models of PBL (2000, 2007) (from Section 2.5), the IRE program includes the following:

- the student learning organized around problems/projects;
- the project as the incentive for the student learning process and is a central principle to enhancing student motivation;
- the projects that are concrete ones that students are attracted to on the basis of their own experiences and interests; and
- the project reflects the conditions of professional practice.

In connection to the Savin-Baden models of PBL, the IRE program has elements from the Model III, *PBL for Interdisciplinary Understanding* with some aspects of Model IV, *PBL for Critical Contestability.*

The focus of the design process is to develop students in all three domains. The description of the design process will focus on student development in the design domain. The IRE design process and its components are depicted in the Figure 4.5 graphic. The model is borrowed from Litzinger (2015). Students often picture the process as the floor plan for a circular house with each area being a virtual room in the home. The first room entered is problem definition.

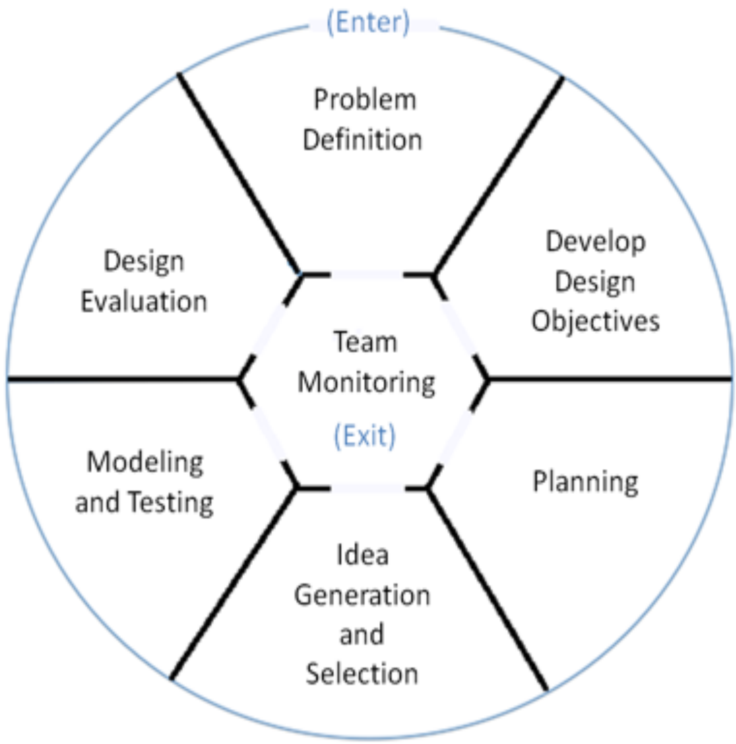

Figure 4.5. IRE Design Process

4.3.1. PROBLEM DEFINITION

Students use the project solicitation form supplied by their client to establish a draft of problem definition. With this draft definition in hand, they travel to the industry site for an initial scoping meeting with the client. At this meeting, they further identify the driving forces behind the design, trying to determine what changes in the clients environment propel the new need. Such factors could include new technical opportunities, changes in regulations, changing economic factors, etc.

Further, the team identifies the requirements and constraints. From the requirements, students are able to understand the necessary components to be included in the final design deliverable for success to be achieved. These requirements should be concise, measurable, and quantified. Constraints are the limiting factors as identified by the client and usually include costs, size, user inputs, standards, regulations, etc. Upon returning from the initial client meeting, the students update their draft problem statement to a final problem statement and then submit it back to the client for approval.

As the students leave the problem definition room from Figure 4.5, they enter the team monitoring room. Each time the group enters this virtual room they ask questions, the answers to which will determine which room they should enter next. A typical question at this juncture might be "is the scope of the problem definition appropriate, considering the time resource available to us?" If the answer to this question is yes, the students would likely move into the "develop design objectives" room. If the answer is no, they will move back into problem definition and, in conjunction with the client, refine the problem definition.

4.3.2. DEVELOP DESIGN OBJECTIVES

The first step in this stage is to identify the needs of the end user. Students will look to interview or survey an appropriate sample of the potential end users of the design. By identifying these needs and quantifying the relative importance of the needs, the students bring an essential component into the design objectives. Using the end user needs and requirements and constraints from the problem definition stage, the team can create a set of goals that, when met, will result in a final design for the client. These goals are referred to as the design objectives. The design objectives should be concise, quantitative, and forward-looking. Design objectives are submitted to the client for feedback to ensure that the team direction aligns with the client desires.

When leaving the design objectives room, students return to team monitoring. Here they compare their design objectives with the problem statement to ensure compatibility. They again check for appropriateness in regard to resources available for completion of the project. Answers here can lead to problem definition refinement, design objective refinement, or advancement to the planning stage. Table 4.4 shows sample design objectives.

Table 4.4. Sample project team design objectives (used with permission, Hanegmon, Benes, and Schumacher)

Objective	Method of Measurement	Target
Safety	Operator can safely utilize system	No operators in confined spaces
Ability to drain system	The system will properly pump the water out of the condenser pits	System will drain the condenser pits as low as top of strainer
Compatibility with Other Systems	The system's performance based on all associated systems as well as other system's performance based on condenser pit's pumping system	The system will be designed to function in accordance with all associated systems
Maintainability	Amount of time and maintenance required once installed	Design for low-cost, time, and effort towards maintenance
Withstands corrosion	Visual inspection after regular use	Withstands regular corrosion
Create supporting documentation	Operating procedure, timeline, updated P&IDs and final document to client will be created	Operating procedure, timeline, updated P&IDs and final document to client will be created
Reliable performance	Operation time without major repairs	System will be designed to an acceptable lifespan according to manufacturer's specifications.

4.3.3. PLANNING

Upon approval of the design objectives by the client, the team develops a detailed project plan. The project is broken into well-defined tasks. Each task has an estimated completion time, person(s) responsible, and start and end dates. The team creates visual representations of the plan in the forms of Gantt charts or Microsoft Project charts. The plan is printed and displayed in the team room for quick reference. The project plan is a dynamic document. Team members continually track project execution as compared to initial timelines. The plan is frequently updated as new tasks arise, old tasks are completed or deleted, and the project continues towards completion.

When the team leaves the virtual planning room for the first time, and enters the team monitoring room, they evaluate the completeness of the plan in regard to the problem definition and the design objectives. Throughout the execution of the rest of the project, the team will return many times to the project planning room to make the updates and track the progress.

4.3.4. IDEA GENERATION AND SELECTION

Central to the act of design is the development of creative solutions to the design problem. It is when entering the virtual "idea generation and selection room" that the team ideates potential solutions to meet the client's needs while operating within the constraints imposed. The key to the idea generation process is extensive research on past works of others and the identification of the engineering fundamentals that dictate the science under which solutions can be developed. Team members work individually or in small sub-teams during initial idea development. As time goes by, the larger team comes together to synthesize ideas and create hybrid ideas.

Following initial idea generation, the team goes through a selection process such as the Pugh matrix method (Pugh, 1991) where they assign weights and values to aspects of each idea, creating a scoring system that allows an aspect of quantification to the selection process. As one or two ideas rise to the top, another round of idea generation begins in which further hybridization can result in improved designs. At several junctures during the idea generation and selection phase, the team retreats to the virtual team monitoring room. There they can evaluate ideas, as compared to design objectives and the design problem statement, and also return to the team planning room to make necessary adjustments to the team plan. See table 4.5 for an example design decision matrix.

When the team ultimately settles on one or two designs that can be brought forward in the design process, they enter the modeling and testing phase.

Table 4.5. Sample project team design decision matrix (Hanegmon, Levar, Nelson, Syzmonowicz)

Concrete Test Procedures								
Brand	Hot Tire	Wear Marks	Oil Test	Slipperiness		Hot Works	Drop Test	Total
Drylok 1part epoxy	2	2	5	3	5	3	3	23
Painters Select premium porch and floor	2	1	5	7	8	4	5	32
Drylok Concrete Floor Paint	4	2	5	0.5	1	2	5	19.5
Rustoleum	1	2	5	3	4	1	5	21
Porch & Floor	0	8	5	3	4	1	5	26

4.3.5. MODELING AND TESTING

When initial designs are selected, the team creates a method to test the designs as to their ability to meet design objectives. Often this testing includes the creation of prototype models and the design of experiments. Students start with a specific plan for modeling/testing where they carefully lay out the purpose of the test and the step-by-step procedures they will follow. The modeling can include physical, non-working models that are used to further ideate aspects of the solution. Such models are made on 3-D printers, laser cutters, or out of foam or balsa wood. More advanced models achieve the prototype level and are working models made out of the materials that are more likely to be used in the actual implementation. Students design and conduct experiments, using the models to demonstrate the ability of the designs to meet initial objectives and constraints. There are many failures of the designs during this stage. Design failures result in a return to the idea generation and selection phase in which design improvements are ideated, then back to modeling and testing for the implementation of the design improvements.

As during the initial idea generation selection/phase, there are several times during modeling and testing when the team returns to team monitoring to check schedule and alignment with design objectives, constraints, and problem definition. Figure 4.6 is an example project team test plan.

Test Plan

General: This document will contain the main design goals that the team would like to meet for the 2015 Mini Baja. It will describe the design objective, the purpose for each goal, and the procedure of how it will be tested.

Weld Test

Purpose of Test: The purpose of the weld test is to test the strength of the welded joints in relationship to the material. According to SAE Baja rules the strength of the welds must be greater than the strength of the material, and therefore must fail before the welded joint when put under load. This test is also to check if the weld is reaching full penetration in the material.

Test Objective: Test the strength of the welded joint by applying a force to the test piece until failure and observing if the failure point is in the material or the welded joint. We will also cut a welded sample and analyze the depth of the weld penetration to assure it is going all the way through the material.

Test Procedure:

1. Cut metal to appropriate length.
2. Perform coping cuts on one end of the metal.
3. Weld the metal in a "T" shape.
4. Put sample piece into the test fixture.
5. Apply force on piece with floor jack until failure as shown in *Figure 1*.

Figure 4.6. Sample test plan

4.3.6. DESIGN EVALUATION

As the team nears completion of the design project, they begin formal evaluations of the design results. Based on the inputs from the modeling and testing phases, they evaluate the final design against all design objectives and constraints. They identify strengths and weaknesses of the design as compared to each objective. From this analysis, students develop a set of design improvements. If time allows, they begin making some of the design improvements. If not, they create a design improvements document that is submitted to the client, along with the final design documentation.

4.3.7. PROJECT COMMUNICATION

Throughout the design cycle, the team is responsible for several forms of communication. These include written documentation, formal presentations, poster creation, informal design reviews, and client interactions. Required written documents include the following: team contract, design problem summary, design concepts document, design selection document, testing plan, and final design evaluation. Formal presentations include these: scoping presentation (after initial planning phase), technical presentation (at mid-semester, detailing the deep use of engineering principles in the design), final design review (formal team exam at the end of the semester, and final client presentation. Informal presentations include the following: weekly design review with project facilitator and periodic client update presentations. Upon completion of the design objectives stage, the team creates a 24” by 36” poster describing their project for public display in the program passageways. Figure 4.7 shows an example of student team project poster.

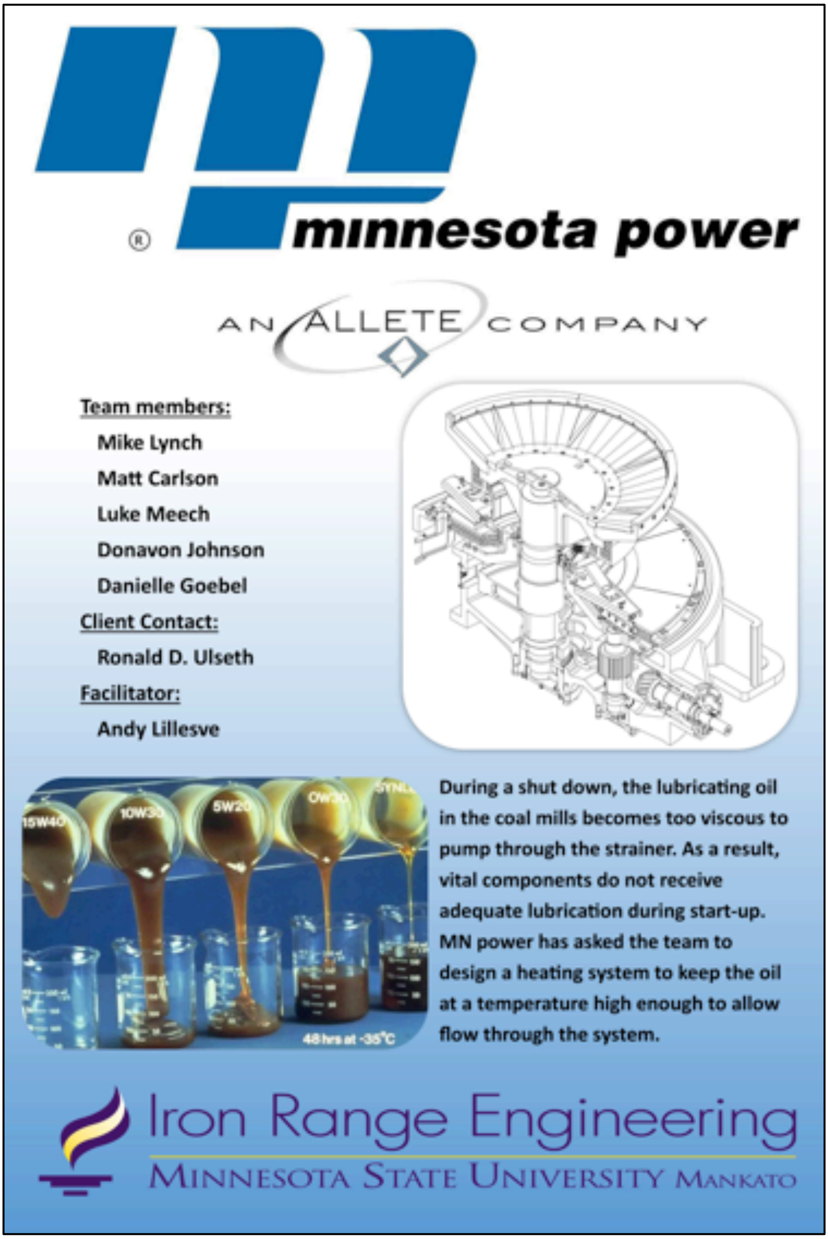

Figure 4.7. Sample project team poster

4.3.8. PROJECT FACILITATION

A member of the Iron Range Engineering academic staff acts as a project facilitator for each team. Usually, there is one team per faculty member. The backgrounds of the facilitators range from PhD academicians to late-career practicing professional engineers, to recent BS engineering graduates of the IRE program. All of these facilitators bring different, valuable perspectives to the academic staff.

The project facilitators serve the team in a variety of functions. They serve as the liaison between the team and the industry client. The purpose of this role is to have a clear understanding of the needs of the client so that when the student groups have a misperception of client needs, the facilitator can guide to a redirection. Their role is not to serve as a middle-person between the client and the team. It is important that the team members maintain full and open communication with the client. So in this respect, the liaison has to work from the side, encouraging the students to act, rather than acting on their behalf. From the client perspective, it is important for the facilitator to manage expectations. Most clients don't know what to expect from the IRE teams. Some expect a level of work far higher than that of which the teams are capable and some expect far lower. The facilitator can communicate with the clients to help them have expectations at which levels the students will deliver. This leads to higher levels of client satisfaction upon project completion. The facilitators clearly set the expectation that project is a learning experience for students, as well as being an asset for the client.

The project facilitator performs the role of design instructor. Students do not enter the program with a full understanding of the design process nor project management, nor how to create innovative solutions. Through a coaching environment, the facilitator guides the students toward advancement in their understandings of the processes and their abilities to execute. The facilitators take a scaffolded approach, providing more structured guidance to new students, removing the structure as the students move through the four-semester program, to a point at which graduating seniors are expected to act with little supervision.

Each week, the facilitator meets with the team for several hours. During these periods, students present informal design reviews, describing and defending their actions and progress from the previous week, current project status, and plans for the upcoming week. Additionally, during this weekly meeting, the facilitator guides student discussions on ethics, contemporary issues, and helps each student track his or her progress on the learning goals. A major focus is the student development of the professional competencies and helping to guide individuals and the team through the development process.

All program facilitators meet for one hour per week to share experiences, discuss the progress of their teams, and provide peer learning and feedback.

4.3.9. TEAM COMPOSITION

The program has experimented with team makeups. This is regarding who selects the team makeup, the academic staff or the students themselves. It is also in regard to the student levels, teams made up of all students from the same level or vertically integrated with new students through graduating seniors. At the time this thesis is being written, the program has settled on vertically integrated teams selected by the students themselves. The advantages of being vertically integrated include experienced students being able to guide newer students through team and design processes. The advantage of student selection of teams comes from students gaining a higher level of ownership in their own educational decisions.

4.3.10. LEARNING THEORY AND RELEVANT ELEMENTS – DESIGN LEARNING

The design learning, as described above, draws from all corners of Illeris' triangle. In the upper left, the content includes the acquisition and practicing of the design process, as well as the technical attributes of the design. In the upper right, motivation is drawn from the real-world importance of meeting a client's need on a project and on a team that the student selected himself. Moving down Illeris' triangle brings into account the interactions within the team and external to the team, as well as how the design interacts with its users. Many arguments can be made about the IRE design experience having attributes in each corner, thus enabling a placement of this process near the center of Illeris' triangle.

The constructivist aspect of the design learning comes from the inter-relatedness between the technical competence students have acquired previously or during the design process. Substantial new knowledge is constructed as students advance their learning of a fundamental principle at the conceptual level to real use in the execution of design. The knowledge constructed at this level is then available for use, and further development, in another cycle of the learning spiral in future projects.

Most of the APA principles come into play in the IRE design learning process. The cognitive and metacognitive factors that are applicable include the nature of the learning process, the goals of the learning process, the construction of knowledge, and the context of learning. The motivational and affective factors are all high, due to the ownership students have in choosing the team and project, and the contextuality due to the perceived importance of the real projects. The team and learning community environments established during the project influence development and social factors.

Important factors in the development of expertise include heavy emphasis on reflection, inquiry, and students inventing and developing instruments to work more efficiently. The design cycle, traversed 4 times by each student, takes place in an environment where facilitators scaffold these factors, specifically during weekly design reviews.

Scaffolding is present in the design learning as new entering students are given much guidance on all aspects of design. Then, slowly, that structure is removed until the students are in their last semester and have the freedom and responsibility to do the process with very little guidance, and are even expected to provide some of the guidance and structure to the most junior members of their teams.

Motivation on design teams and projects is high, due to many factors: student ownership in decision making, contextuality provided to all other learning domains, reality of the use of their products by clients, and the high expectations of the clients.

The design learning experience highly influences the situativity of their learning. The environment of the project room, fabricating labs, and industry site, the artifacts and communities of which they are a part, and the actions of professional practice all cause the learning to be distributed among the learners and everything around them.

The design team, their facilitator, and their clients form a unique learning community. The members share many of the same learning goals, activities, physical spaces, and spend much time together. These communities build anew, each semester, and are centered on the design project. Students are given special instruction on how to develop stronger teams through activities and respectful actions. Their success in building strong communities impacts their design success and overall learning.

The act of performing engineering design on a team for a real client and creating tangible products and systems that will be used by the client, all while doing so in an environment that has been designed to simulate professional practice, creates the opportunity for members of the team to develop higher levels of identity. The level to which the identity increases is dependent on the mindset of the individual and her peers, as well as the facilitator and the client.

As the discussions on the team projects progresses and the IRE design process transitions into focusing on the student learning in Section 4.4, it is important to emphasize the importance of the project facilitator. The academic staff not only oversees the project itself and facilitate student learning of the design domain outcomes, but they are an integral part of students connecting their technical and professional domain learning to their project work. As students generally enter an engineering curriculum with little to no experience or training in functioning as a team, or how to manage projects, it is important to have someone to guide them through this process.

4.4. STUDENTS' LEARNING

In the traditional *discipline and teacher-controlled approach,* student learning is focused on knowledge acquisition; and the motivation for any collaborative learning is for each individual's learning. Students entering these types of programs are typically not provided with instruction on "how to learn."

In contrast, the *innovative and learner-centered approach* is characterized by the student learning being more about the construction of knowledge and understanding, with the collaboration between students being focused on creating knowledge with others for the benefit of all. In a PBL curriculum, a student-learning structure exists to support the students acquiring the program learning outcomes. Students typically enter the program with experience learning as individuals, with little experience learning in a team and learner-centered environment. Critical to student success, in a PBL model, is the incorporation of support courses that develop student attitudes and expectations towards the PBL model of education while also developing their abilities to learn in the collaborative learning environment.

Placement on Spectrum

In the development of the IRE model, a choice was made to focus on creating learning experiences and activities that develop students' knowledge in the technical and professional domain that directly support the project work. The intent is that the collaborative learning within the project teams is focused on constructing knowledge for both the completion of the project and for the team members to achieve the program learning outcomes, which they are focused on for that given semester. With this focus, the IRE model lies at the *innovative and learner-centered approach* end of the spectrum as shown in Figure 4.8.

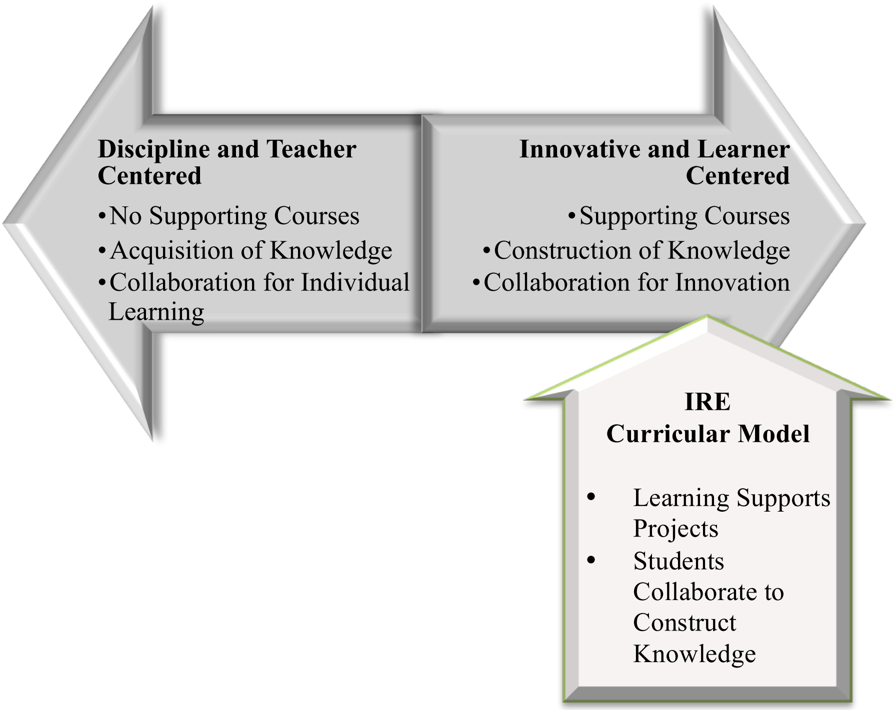

Figure 4.8. Types of students' learning spectrum

Characteristics of IRE Model

This section will specifically look at the IRE model approach to students achieving the technical and professional learning outcomes. It will close with the role of the IRE social culture on student learning in all three domains.

4.4.1. TECHNICAL CURRICULUM

Technical learning makes up 32 out of the 60 semester credits in the IRE two-year program. Students average 8 technical credits per semester. Each credit is a stand-alone course, referred to by IRE students and instructors as a "technical competency." Of the 32 competencies, 16 are deemed as "core" (required by every student) and 16 as "advanced" electives. Core courses include thermodynamics, material science, fluid mechanics, manufacturing processes, dynamic systems, mechanics of materials, instrumentation, electronics, electric machines, digital logic, AC, controls, entrepreneurialism, engineering economics, statistics, and programming/modeling. It is through the makeup of the advanced competencies that a student can choose depth, to focus on a particular area of engineering, or choose breadth to become more of a generalist. All students earn a Bachelor's of Science degree in Engineering (BSE). Students who take 14 out of 16 credits in a depth area can earn an "emphasis" in that area. The emphasis comes in the form of a department letter describing what their emphasis is and what competencies and projects they completed. Emphases have been awarded in mechanical engineering, electrical engineering, biomedical engineering, chemical engineering, and engineering management.

4.4.2. TECHNICAL COMPETENCY SELECTION

Students have control over which competencies they take each semester. They receive guidance from the program director during seminar and individual guidance from both their advisor (an academic faculty member they are assigned to for their four semesters) and their project facilitator (an academic faculty member who guides their project during a given semester). As students decide which competencies they will pursue each semester, they have two objectives they are trying to meet. The objectives are choosing learning that benefits their semester project and choosing learning that is aligned with their desired depth emphasis area. Most often there is overlap between these objectives. Most student projects align with their desired depth emphasis. The courses are delivered in two half-semester periods called "blocks." At the beginning of the semester, students decide which four competencies to take for the first block. Then, at mid-semester, they select four competencies for the second block. The goals of this system are to provide flexibility and student ownership. By choosing which competencies to take when it makes the most sense for the project, the students have the opportunity to have high levels of contextual relevance. Again, it is mentioned that academic staff are available to provide guidance when students are unsure of what is the most appropriate set of competencies to pursue.

4.4.3. TECHNICAL LEARNING PROCESS

The first day of each competency is called "syllabus signing day." To this conversation, the students and the instructor bring their hopes and expectations for the course. Together, they discuss these expectations and design the layout of the course in terms of learning activities, deliverables, and evaluation. Figure 4.9 details the expectations of a day one conversation.

Day 1 Learning Conversation Expectations:

- Faculty member brings electronic copy of updated syllabus
- Discussion of:
    - pre-requisite knowledge
    - student learning goals
    - faculty learning goals
    - DLA expectations and plans
- Daily expectations for students and faculty
- Rough draft of timeline
- Day 1 homework assignment
- Print and sign syllabus

Figure 4.9. Day 1 learning expectations

A typical competency has 10-15 students and one instructor. The instructor and the students will meet two – three hours per week for six – seven weeks in "Learning Conversations" (LC). A learning conversation is a time during which students and instructors can make conceptual sense of the learning. This is done in flipped-classroom type of method in which students do initial learning between LCs and then use the time together in LCs to ask questions and discuss the relevance of the learning. The three required learning types in any competency are conceptual, process, and metacognitive.

Conceptual learning is focused on connecting all learning to the fundamental principles of engineering. For example, if students were taking a competency in heat transfer, they would learn the concepts of conduction, convection, and radiation. Then they would connect these concepts to broader engineering fundamentals such as the law of conservation of energy and the 2nd law of thermodynamics. Learning activities in conceptual learning include reading, watching on-line videos, working problem sets, creating concept maps, and discussion.

In *process learning,* students connect their conceptual learning to engineering practice. They do this by completing a Deep Learning Activity (DLA). Whenever possible, the DLA is work done in the design project such as design, testing, or modeling. For some examples, we can return to the learning of heat transfer. It is not unusual for IRE project teams to be designing heat exchangers for their clients. The act of completing that design would be a DLA for a heat transfer competency. Another example, if heat exchanger design were not required, would be for the students to design and conduct an experiment verifying heat transfer, using physical equipment and instrumentation. As the domain of learning spreads across all of engineering, similar type process learning opportunities are found in abundance. During learning conversations, instructors help students make connections between their conceptual learning and their DLA, as well as provide technical assistance to students during their DLA.

Metacognitive learning happens through students planning their learning, organizing and reorganizing their factual and conceptual knowledge, reflection, evaluation of their learning, and using the reflections and evaluation to dictate future learning. Each student keeps a learning journal for every competency, in which they record this planning and organization and write the reflections and judgments. At the end of each block, students write a metacognitive memo analyzing their learning during the four competencies, and making future learning goals. Appendix D details the metacognitive learning process at Iron Range Engineering.

4.4.4. LEARNING THEORY AND RELEVANT COMPONENTS – TECHNICAL LEARNING

Certainly, technical learning is about content. However, the action of acquiring and then using that knowledge is greatly impacted by incentive and interaction. These three make up the corners of Illeris' triangle, with content in the upper left, incentive in the upper right, and interaction at the bottom. The content in the technical learning is focused on the conceptual understanding of the fundamental principles of the discipline. The act of learning, for most students, requires incentive, an understanding of why they want to learn the material, a motivation for the action. At IRE, the incentive for technical learning comes from one of two major areas. The incentive is either to acquire the knowledge so that it can be used in the design or to acquire the knowledge as part of reaching their desired competence in the chosen area of technical depth. In the IRE model of technical learning, interaction happens in small groups of students and instructors who are working together to first acquire the competence, and then to use it in the DLA. This interaction is between the learner and his environment and between the learner and her peers/instructors. This distribution of actions within the IRE technical learning process argues for learning to be near the center of Illeris' triangle.

IRE technical learning is constructivist in nature. Rather than delivering the conceptual information to the students in a lecture, instructors guide students to build conceptual models by using motivation, conversation, and application. Students perform daily reflection and organization in their learning journals. The goal, by the time of the oral exam, is for the students to have created a technically accurate conceptual model that they can first describe to themselves and then verbalize to their instructor. The deep learning activity allows the student to experiment with using the knowledge in a, usually physical, process in which they can observe interactions and draw conclusions.

Nearly all 14 of the APA principles are in play in the IRE technical learning model. Starting with principle 1 in which learning is “an intentional process of constructing meaning from information and experience” through setting learning goals, strategic thinking, thinking about thinking, and contextual influences. Instructors set up a learning environment with many opportunities for high levels of motivation, including creating novel and challenging tasks relevant to personal interest, while providing for personal choices and control. Further, the learning has many social influences through interactions with peers and instructors. The IRE model adapts to the individual differences in learning and accounts for differences in cultural and social backgrounds. Finally, the technical learning is done with regard to high and challenging standards, while providing substantial feedback during the learning process.

Developing expertise is a goal of the technical learning model. The attributes of learning that lend to expertise development are thinking about thinking, focusing on the fundamental principles, and doing so through inquiry.

Formal reflection is an everyday part of IRE student technical learning. This is done in an attempt to develop graduates capable of reflecting-in-practice; so they can descend into the complex, ill-structured problems associated with Schön’s swamp, as described in Section 2.4. Further, through the IRE metacognitive process, students spend time thinking how they learn, how well they learn, and how they can learn better. Reflection and metacognition are explicitly developed attributes in students during their technical learning.

During the learning conversation process, the instructor treats the students like apprentices learning a trade. Using scaffolded guidance, questioning, and answering, instructors promote the students’ active participation in the development and achievement of their learning goals.

Situativity distributes knowledge “among people, their environments, objects, tools, books, and communities” (Greeno et al., 1996). In the IRE technical learning environments, the community, the physical space, and the objects of learning are emphasized and designed for effective learning. Students are continually placing their daily learning with representations, aligning with professional practice, and using their learning in design. This situativity leads to the building of identity, through alignment, with the people and actions of professional practice. Identity is further emphasized by approaching technical learning in a self-directed manner, just as engineers in practice are expected to do, on a daily basis.

4.4.5. PROFESSIONAL CURRICULUM

Professional learning activities include ethical discussions, performing outreach, leaderships, communicating in writing, verbally and graphically, learning to succeed in a diverse environment, becoming aware of contemporary issues, developing a personal marketing plan, practicing career searches, and meeting the professional competency expectations of an IRE student. Almost all of the professional learning takes place in conjunction with the activities of the design project. Ethical discussions take place in context with the engineering work being done on the project. Writing, presenting, and making graphical representations are executed for the written, presentation, and poster requirements for the design project. Contemporary-issues-learning has an engineering and technology slant. Design teams can include relevant contextual aspects, such as economics, sustainability, environment, social, and political aspects in their design solutions. The daily interactions between students, and between students and academic staff, are expected to take place at high levels of professionalism. See Figure 4.10 for the professional expectations of an IRE student.

Professional Expectations of IRE Students and Staff

As members of the IRE community, we are expected to act professionally with one another and with people external to the program.

Below is a list of important professional behaviors that an IRE student should follow.

When anyone in the program is acting unprofessionally it is important that he/she is informed—this is the responsibility of everyone, and should be done in private.

1. Pay close attention to our emails – acknowledge their receipt, act on requests.
2. When told something, write it down and ask questions for clarification.
3. Arrive at all class periods on time – being respectful of time.
4. Dress and groom appropriately.
5. Treat all others with respect.
6. Maintain a positive attitude.
7. Do not take frustrations out on those around us.
8. Work hard to create an environment free of harassment.
9. Willingly help others inside and outside of IRE.
10. Speak professionally, free of vulgarities, and with appropriate grammar.
11. Meet all deadlines.
12. Meet the needs of our teams by completing work on time and of high-quality.
13. Give proactive feedback to others.
14. Be willing to accept and give constructive criticism.
15. Keep IRE clean – Both personal and common spaces.

Figure 4.10. Professional expectations of IRE students and staff

Professional learning is seen as a continuous process from entry into the program until graduation. During the first semester, students begin the creation of their own

Professional Development Plan (PDP). The PDP has eight sections:

- Functioning on a team
- Communicating in writing
- Presenting
- Acting ethically
- Being professionally responsible
- Leading
- Learning about learning
- Being Inclusive

In each section, the students evaluate their current level of performance, providing evidence of their judgment, set goals for improvement for the next semester, and write an action plan for achieving the goals. Table 4.6 shows the scale students use for these self-analyses.

Table 4.6. Professional development plan self-assessment scale

Performance Levels				
1 = Deficient	**2 = Weak**	**3 = Acceptable**	**4 = Desired**	**5 = Exemplary**
Shows little evidence of desired performance, clearly not acceptable for IRE graduates	Shows some but inadequate evidence of desired performance needed in IRE graduates	Shows moderate evidence of desired performance, minimally acceptable for IRE graduates	Shows strong evidence of desired performance, clearly meeting high expectations of IRE graduates	Shows unusually strong evidence of performance as a skilled professional, exceeding expectations of IRE graduates

Every semester there are several learning activities that empower students to achieve growth in each of these competency areas. These learning activities include the following: workshops by external experts, workshops by IRE academic staff, peer discussions, assigned readings, student presentations, videos, and personal reflection. In addition to learning opportunities, there are multiple methods for feedback on development. Examples include daily informal feedback from faculty to students, formal peer reviews, formal personnel evaluations from project facilitator to each team member at the end of the semester, and grading of various professional documentation submittals. The PDP is a comprehensive document; wherein, each semester the student adds her or his new assessments, goal, and action plans, allowing for visible changes in development throughout the education. See Table 4.7 for an example section from an IRE student's PDP.

Table 4.7. Sample chapter from an IRE Student PDP (used with permission, Olafson)

Function on a Team	Current Evaluation	For this expectation of an IRE student, I would place myself as a 4 on the scale. I believe that through my Co-Op and other team activities, I have progressed from an acceptable team member to a desired team member. This semester I have progressed in my teamwork skills through my Co-Op, by balancing the needs of multiple companies simultaneously. I also had the opportunity to attend a teamwork conference in Seattle with the other three Co-Ops. This conference was immensely rewarding and I have already started applying what I learned there. Next semester I will be working on an IRE team for my final project.
	Goals	Next semester I will be working on an IRE team after spending a year as a Co-Op. Although I did expand my teamwork skills while I was working for PolyMet, working on a team at IRE for my last semester will allow me to further develop my teaming skills. I would most like to work on: 1. Accepting and giving constructive criticism. 2. Learning when to assert myself as a leader, and when to take a more passive role. 3. Share responsibility and praise for all the team members' mistakes and good work.
	Action Plan	1. I have specific actions I will take next semester in order to fulfill my goal to work on accepting and giving constructive criticism. • The first step I will take will be to use the peer review form from Traci and Christine every week, not just the two assigned times. • I also will work toward having an open communication in design reviews where we can openly discuss the strengths and weaknesses of the team. • I will seek mentorship from the faculty, especially from my project facilitator. I will tell them to share any constructive criticism they have for me throughout the semester. 2. At the beginning of the semester when we develop the Gantt chart, each team member takes responsibility for certain tasks. • I will assert myself on the tasks for which I am responsible. • I will not undermine the leadership of others on their tasks.

		• I will not interrupt when my teammates are talking, and be open to their ideas. 3. It is important to present the team as a united front. • When there are mistakes made on my team, I will not place blame. I will say that the team made a mistake, not a particular person. • When we have successes, I will attribute it to the entire team, and not try to accept personal praise.

4.4.6. LEARNING THEORY AND RELEVANT COMPONENTS – PROFESSIONAL LEARNING

If a person were to describe a concrete mix in terms of its ingredients, it could be considered as being made up of coarse aggregate (rocks) and fine aggregate (sand) with a chemical mixture of cement and water filling in all of the fine gaps between the rocks and the sand. For analogy, if we were to look at design learning and technical learning as the rocks and the sand, then professional learning could be seen as the cement-water mixture. Professional learning fits in between and around, providing essential support for design and technical. The essential professional competency aspects of communicating, leading, managing, and acting professionally and ethically all happen in and around the design and technical learning, giving them strength just like the cement gives strength to the concrete. Professionalism is integral to supporting the learning of design and technical competencies. The learning of professionalism also has both dimensions of Illeris' learning model – internal interactions and external interactions. Communication is key to professional learning and is essentially the vertical leg of external interaction. Internal interaction moves along the continuum of content to incentive. The PDP epitomizes this continuum. In the PDP, students have to describe the content of their learning and thus discuss its importance in their careers, followed by making plans for how to improve the learning of content and the why, all the while communicating this to their external audience. Yet again, the professional learning at IRE moves toward the center of Illeris' triangle.

The learning of professional competencies is highly constructive. The students use their development action plan with injections from external sources, such as workshops, printed or digital media, feedback from peers, and feedback from supervisors to construct their new professional identity and set new goals and action plans. This cycle repeats itself over four semesters, as students continue to build their personal professional identity and self.

While the nature of professional learning is quite different from the nature of technical learning, the principles of how it is learned are quite similar. Using the APA principles it can be seen there are cognitive/metacognitive factors, motivational/affective factors, developmental/social factors, and individual factors all associated with the acquisition of professional competence. While the domain is different, the learning factors are the same.

An attribute of adaptive experts is a proficiency at reflecting on thinking during the thinking processes. Educational environments that lead toward the development of adaptive expertise have students perform substantial reflection and metacognition. The PDP process, which is an essential component of the professional learning environment at IRE, is, by its nature, a reflective and metacognitive learning activity. Feedback from graduates and employers of graduates is that they are further along the developmental spectrum from novice to expert than are their peers from other learning models.

Scaffolding is key to all three domains of IRE learning. In the professional domain, new students are provided with much structure; whereas, graduating seniors are free from nearly all guidance. For those new students, faculty and more senior students act as role models, give guidance, and give feedback on expectations and levels of performance.

IRE students tend to be highly motivated by being recognized as professional practitioners of engineering work. There is a symbiotic relationship between identity and motivation, in regards to professional development. Motivation builds identity, which in turn tends towards more motivation.

The situativity of learning professionalism in situ with learning technical and design competencies, in contrast to learning the same skills separated from practice, provides for a deeper, longer lasting competence. As an example, most new engineers took a class in technical writing sometime during their education. However, that class was disconnected from the technical and design learning in their other courses. The skills from that course tend to be less accessible and less transferable than when the learning and feedback on technical writing takes place on the communication of the actual design, and technical learning happening in other courses. This is how technical-writing learning happens at IRE.

4.4.7. IRE SOCIAL CULTURE EXPECTATIONS

The IRE social culture is designed to be inclusive, collegial, and professional. One of the mottos at Iron Range Engineering is “we learn engineering by practicing engineering the way we will when we become engineering practitioners.” As such, there is an expectation that all daily interactions between all members of the community will be at a professional level. The level of dress for all members of the community is business casual for most days, business formal when we have external guests, and college casual on Thursdays.

There is an expectation of shared ownership of the facility. Project rooms are expected to be clean and organized at the end of each day. Any person who uses the laboratory or common spaces is expected to leave the space neat and organized after its use.

Titles are not used in daily verbal communication. All members (students, faculty, and staff) of the community are on a first name basis. When discussing the importance of succeeding in a diverse environment, students are asked to define in what daily work environment they desire to work after graduation. The attributes tend towards welcoming, happy, positive, and encouraging. The social culture at IRE is expected to have the same attributes. When visitors come to IRE, titles are used as a means of introduction.

Formal and informal student life events are an important aspect of the IRE social culture. There are formal student chapters of professional societies that meet frequently, giving students leadership opportunities, outreach opportunities, and deep career exposure. The staff member who coordinates student life organizes many trips, per semester, for the purposes of entertainment, exercise, or further industry exposure. Informal student life examples include student-led gatherings to work out, watch movies, or volunteer in the community.

Connecting to learning theory and learning environments, the social culture is composed of a collection of multiple learning communities that empower social constructivist learning. The interpersonal relations, communication, and social interactions influence the learning in all domains.

As Section 4.4 concludes, it is important to recognize the significant process that students go through from being the type of student they are when they enter the program compared to the type of self-directed learner they become. They will demonstrate deep areas of expertise within the design, technical, and professional domains. This process is the result of an intentional, purposeful, and guided set of experiences to authentically bring students to this point. Just as this process is different from the learning experiences from which the students come, so also it is different from the process by which most of the faculty and staff have experienced in their education and professional lives. Therefore, it is critical to be just as intentional and purposeful in guiding them through a set of experiences, which will allow them to be successful in this environment. Section 4.5 will focus on this aspect of the IRE model.

4.5. ACADEMIC STAFF AND FACILITATION ELEMENT

Given that most faculty will work more in silos with little “across course or discipline” interaction in most *discipline and teacher centered* approaches, there is limited need for preparation of the academic staff and need for collective facilitation of curricular elements within traditional education programs. In a more *innovative and learner-centered* curriculum, faculty will require a greater degree of academic staff coordination. Innovation means ongoing change in the organization and the culture and, as identified in Section 2.1, this always require equipping people to be successful in this new culture. A specific prevalent need for them to develop in a PBL curriculum is the role of being a project supervisor or facilitator (Kolmos, Du, Dahms, et al., 2008; Kolmos, Du, Holgaard, et al., 2008). Likely this is something they have never encountered before. Given the innovative nature of the IRE program, within the U.S. engineering context, and the program starting from a clean slate, this element is a critical part of the IRE model success.

Placement on Spectrum

A previously existing model, or program for facilitating faculty (academic staff) development, was not identified at the beginning of the IRE program development to provide them with the training they needed in their new roles. Instead, a choice was made to develop a continuous improvement model that would periodically identify and address areas for improving education approaches and practices. To facilitate this, the faculty were officed in a common faculty office space or office suite. The use of this innovative development process for the academic staff and facilitation, places the IRE model fully towards the *innovative and learner-centered* end of the spectrum, as show in Figure 4.11.

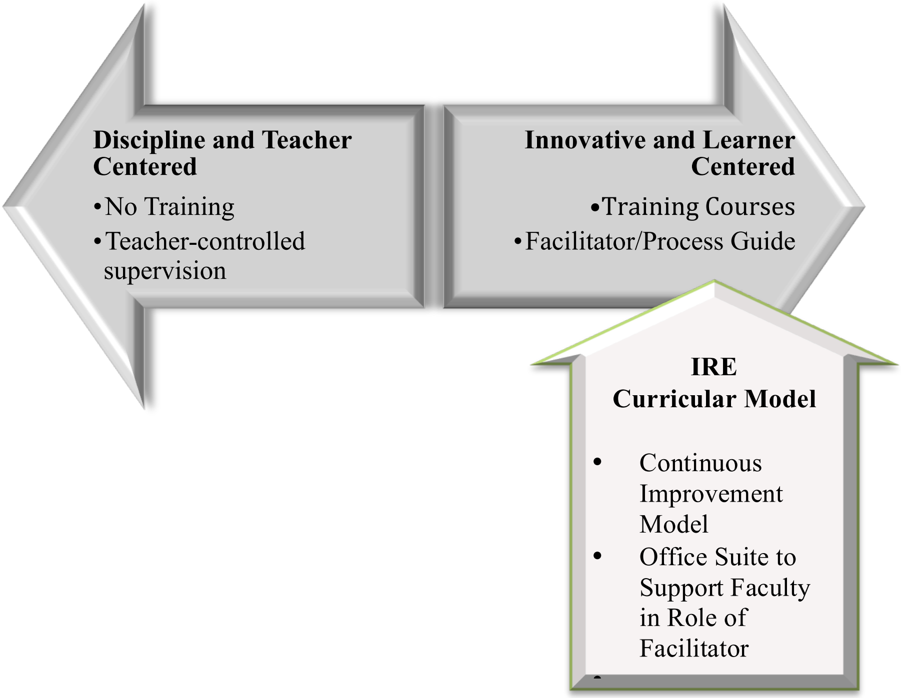

Figure 4.11. Academic staff and facilitation spectrum

In engineering practice, continuous improvement of products and designs is essential to remaining competitive. In a manner consistent with this professional practice expectation for students, the IRE PBL program has adopted that philosophy for academic staff to work together in a collaborative manner, as professionals, would in industry. This approach has resulted in a collaborative *continuous improvement approach* for IRE.

Characteristics of IRE Model

Since the first semester of operation in 2010, the program has continuously evolved, using a model that takes inputs from all constituencies. The program started by using ideas based on theories of how learning should work and by observing successful models that others have employed. Referring back to Schön’s high ground vs. swampland, the program started on the high ground. Within days, the initial faculty found themselves in the swamp, having to deal with the realism of complexity that came with doing something the faculty didn’t know how to do, and the students weren’t accustomed to doing. The trajectory started with much openness and little structure.

The key to success, at the beginning, was openness by the program and the academic staff to listen to students, themselves, and the expert advisory boards. It was essential to analyze what was working, what wasn't, seek advice for change, and create new strategies. The technical, design, and professional learning described previously is the current evolution. It is slightly different than a semester ago and slightly different than a semester into the future, much different than two years ago and much different than it will be two years into the future.

The continuous improvement approach starts by inviting external guests to campus to observe learning activities and interact with students and faculty every semester. Regular visitors include highly recognizable experts such as Dr. Jeffrey Froyd, Dr. Denny Davis, Dr. Edwin Jones, Dr. Sheri Sheppard, Dr. Tamara Moore, the late Dr. David Jonassen, Dr. Rose Marra, and Dr. Carolyn Plumb. The total number of visitors each semester is usually above five. Over 30 different external guests have been to visit. Each of these experts makes a report of their observations and suggestions for future improvement. Another set of external suggestions comes from an industry advisory board, comprised of engineers and managers from client partners. In the last week of each semester, a 90-minute open discussion is held with the student body. In small groups, they identify trouble spots and then develop suggested action plans for improvement. All ideas are collected. Individually, each staff and faculty member keeps a running list of her/his own ideas for improvement. Additionally, graduating seniors submit a "best works" portfolio including works that meet all of the performance criteria for each of the 14 student outcomes. These portfolios are scored internally and externally against appropriate rubrics. The results of this portfolio analysis, showing which outcomes are being met and which need to be addressed, are also an input to the continuous improvement process.

The day after the semester grades are submitted, the faculty and staff hold "Faculty Summit 1." At this summit, all inputs are categorized, discussed, and labeled as must do now, might do now, should consider in future semesters, or not possible/applicable. Faculty and staff divide the potential improvements and take responsibility to draft action plans.

In the week preceding the new semester, "Faculty Summit 2" is held. All of the action plans are presented and discussed. When consensus is reached on new improvements, they are put into the syllabi, student handbook, or faculty handbook, as appropriate. The improvements are presented to students at the opening session on day one of the semester and put into operation for the semester.

The cycle then begins again. Examples of processes that have undergone substantial change as a result of this process are the model used for design learning, physical spaces, presentation formats, the student metacognitive processes, student life opportunities, final exam formats, and many smaller changes. All suggested improvements are tracked, over time, in an observation-action-result table. See

Tables 4.8 for an excerpt from an OAR table.

Table 4.8. Sample observation-action-result tracking table for continuous improvement

Observation	Action	Result
Have mentors review PIP of students from the previous semester to guide and monitor improvement	Faculty handbook	Pending
Continued support for dealing with teammembers who don't meet expectations. Goal is to not have people that no one wants to work with.	Not yet implemented	Pending
Attendance - keep attendance for all Professional and Seminar Activities that require Participation and Reflection grading.	Create Sheet For Attendence	Pending
A comprehensive way to integrate professional writing expectations into all graded documents. IEEE style required?	Not yet implemented	
Academic Integrity Policy - needs to be written, communicated to students, and applied	Needs to be written and added to the wiki	Pending
Faculty/mentors should provide written feedback on individual documents timely so there is plenty of time to integrate this feedback into Final Tech Document.	Encourage timely feedback from mentors	Not much change
Instruct on Linked In and other social media as job search tools.	Not yet implemented	
"Yellow sheet" - add a section for "Receives feedback and constructive criticism well" or not!	Added to the document	Pending
Instruct students on evaluating credibility of internet resources. Workshop on research methods using university databases and industry technical journals. Encourage students to verbalize original source rather than "I found this online"	Not yet implemented	
Emphasize talking like an engineer. Columns for each: 1) Normal Speak; 2) College Speak; 3) Engineer Speak; 4) Geek Speak. Worst offenders could be starred!	Done	Commendations from external visitors
Final Oral Exams: change topic each semester	The format has changed	No longer an issue
Create common technical document template similar to PDP template	Common syllabi were created	Helped with familiarity
Better define expectations for professional journal entries	Create the "four questions" to be answer in the journal	Students still need to be reminded to use them
Start doing sections of PDP and Outcome portfolio earlier in the semester	Create document day	Helped students stay on top of deliverables
Have a larger emphasis on team building before actual work on the project starts and throughout	Addressed in student life	Pending
Consistently enforce professional expectations	Addressed in faculty meeting	Still needs to improve
No "surprise" learning seminars (classes).	Encourage faculty to create a learning schedule	Added to syllabi

An essential element of the continuous improvement approach is the collaboration amongst the faculty and the consistency of messaging to the entire IRE community. The collaboration among faculty is facilitated by the summits mentioned above, but on a daily basis the common faculty office suite, Figure 4.12, creates a natural environment for faculty to collaborate informally on a daily basis. It provides support for faculty as they learn how to guide the complexities of student learning in the PBL curriculum.

The academic staff attends the weekly seminars, shown in Figure 4.13; providing an opportunity for all members of the IRE community, students and academic staff, to hear the same message regarding ideas such as professional development topics. This allows all academic staff to be able to reinforce those concepts, through learning conversations and informal dialogue, with students throughout the week.

Figure 4.12. Faculty office suite

Figure 4.13. Seminar room

Critical, to the development of the academic staff and their abilities to facilitate the teams and the student learning, is the continuous improvement approach and the physical space of the office suite. The physical space is just as critical to the student learning experience. Section 4.6 will look at the overall physical space and organizational structure of the IRE model.

4.6. SPACE AND ORGANIZATION

The physical space and institutional organization have to support the PBL curriculum. What is sufficient in the *discipline and teacher-controlled* curriculum will not be conducive to supporting a PBL curricular approach. Having administrative, organizational, and physical space fully supporting the PBL curricular model is essential to the *innovative and learner-centered* approach.

<u>Placement on Spectrum</u>

The Iron Range Engineering program is unique in that it started from the beginning, with administrative support, to build a new and innovative PBL model of engineering education. Shortly after starting, new physical space was constructed, and former space was remodeled to fit the new program. This allowed choices to be made, within budgetary limits, to develop a physical space that directly supports the curricular approach of PBL. The unique full-on administrative support and physical space construction (to support PBL) uniquely places the IRE model on the *innovative and learner-centered* end of the spectrum, Figure 4.14.

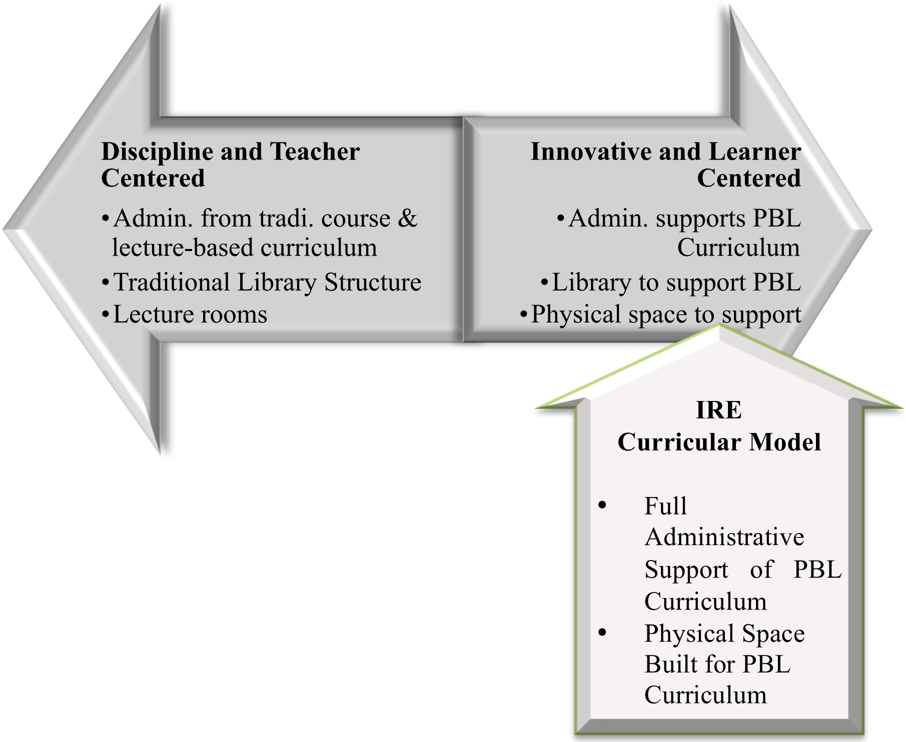

Figure 4.14. Space and organization spectrum

<u>Characteristics of IRE Model</u>

The IRE program has five different kinds of physical space: project team rooms, laboratories, community spaces, office suite, and the seminar room. See Figure 4.15 for a layout of IRE physical space. Project rooms are modeled after the team rooms at Aalborg University. The purpose is to have a physical space in which students have their own offices, a place where the team has access 24 hours per day, seven days per week to work on their design project or their individual learning.

> *"The group room (is) the physical field for accumulation of social and cultural capital. This process is individual as well as common and involves sharing of capital. Participating in the common accumulations process creates a feeling of belonging besides the 'competition' betweengroup members for own values and ideas. In most groups this feeling grows stronger and stronger during the lifetime of the group and creates a positive attitude towards the learning environment. The*

learning environment is synonym with the project group environment." (Spliid & Qvist, 2007)

Figure 4.16 is a photo of an IRE project room. Weekly design reviews take place in the room. The walls are filled with whiteboards and project oriented posters. Each student has his or her own desk and bookshelf. This proximity provides for substantial team interaction, which empowers team development and project advancement.

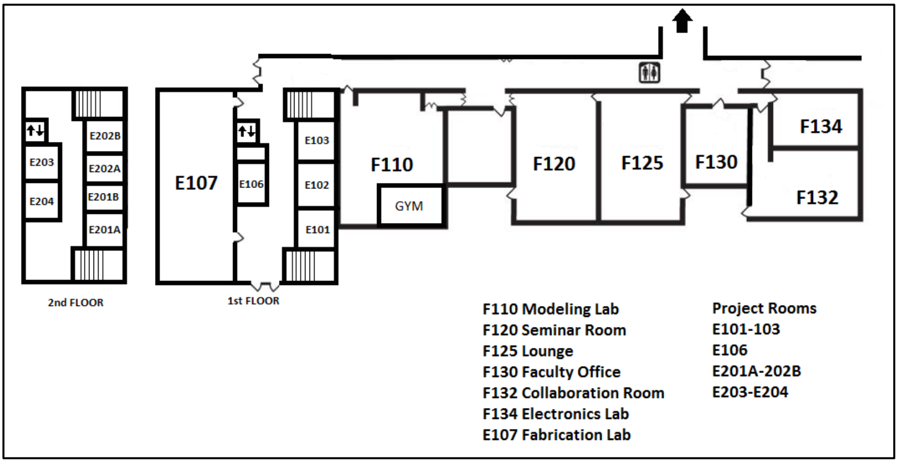

Figure 4.15. Layout of IRE physical space

IRE has three laboratory spaces: an electronics lab, a modeling lab, and a fabrication lab. The electronics lab (see Figure 4.17) is a traditional laboratory space in which students can learn and experiment with electrical, controls, instrumentation, PLC, and electronics concepts. The modeling lab (see Figure 4.18) is a modern conceptualization space for creating physical, non-working models, using devices such as a laser cutter or rapid prototyping machine. The fabrication lab (see Figure 4.19) is a large space for building working prototypes, using advanced fabrication tools such as CNC lathe, CNC mill, water-jet, manual mill, various types of welding, and a wide assortment of hand and bench tools.

IRE has several community spaces where students and staff integrate on a frequent basis to socialize, gather for learning conversations, or take part in student life activities. The spaces are a student lounge (see Figure 4.20), a small exercise room, and lobby spaces (see Figures 4.21 and 4.22).

The academic staff share one office suite (see Figure 4.14). Similar to a team project room, the office suite allows the faculty to regularly interact with each other in a synergistic way. Students are welcome in the office suite at all times, with the intent of having an inclusive student-faculty community.

The seminar room (see Figure 4.16) is the one place where the entire community gathers at one time. This usually happens three times per week. Monday mornings, from 08:00 to 10:00, students and academic staff gather for "seminar", a class for professionalism workshops or student presentations. Wednesday mornings, students gather for practicing closed-ended problem sets in preparation for their engineering licensing exam, which they will take near graduation. On some Friday afternoons, industry speakers join the program for a lunch prepared by the students, and then they give a 30-minute speech about their industry and their personal career.

The physical space supports learning through influencing the social factors, context of learning, instructional practices, identity, and community building.

Figure 4.16. Sample IRE project team room

Figure 4.17. Electronics laboratory

Figure 4.18. Modeling laboratory

Figure 4.19. Fabrication laboratory

Figure 4.20. Lounge

Figure 4.21. Downstairs lobby gathering space

Figure 4.22. Upstairs lobby gathering space

4.7. ASSESSMENT AND EVALUATION

Assessment is a core driver in the student learning process. This final curricular element is important in understanding the placement of the IRE model with the PBL curricular model. As compared to the *discipline and teacher-controlled approach*, in which the assessment is focused primarily on the individual and the summative knowledge gained in a course, the *innovative and learner-centered approach* focuses on assessment that supports the collaborative learning of the project team. Thus, the assessment focuses on the team being assessed while still maintaining the grading of individual performance. Formative assessment methods are a critical part of this assessment process and keep a focus on the student awareness of the learning process.

Placement on Spectrum

A choice was made in the development of the IRE model to develop an assessment and evaluation practice that supported the ideals of the *innovative and learner-centered approach.* It focuses specifically on oral exams, group assessment, and formative assessment tools and methods. This places the IRE model on the *innovative and learner-centered* end of the spectrum, as shown in Figure 4.23. The assessment of the design, technical and professional competencies will be discussed in this section.

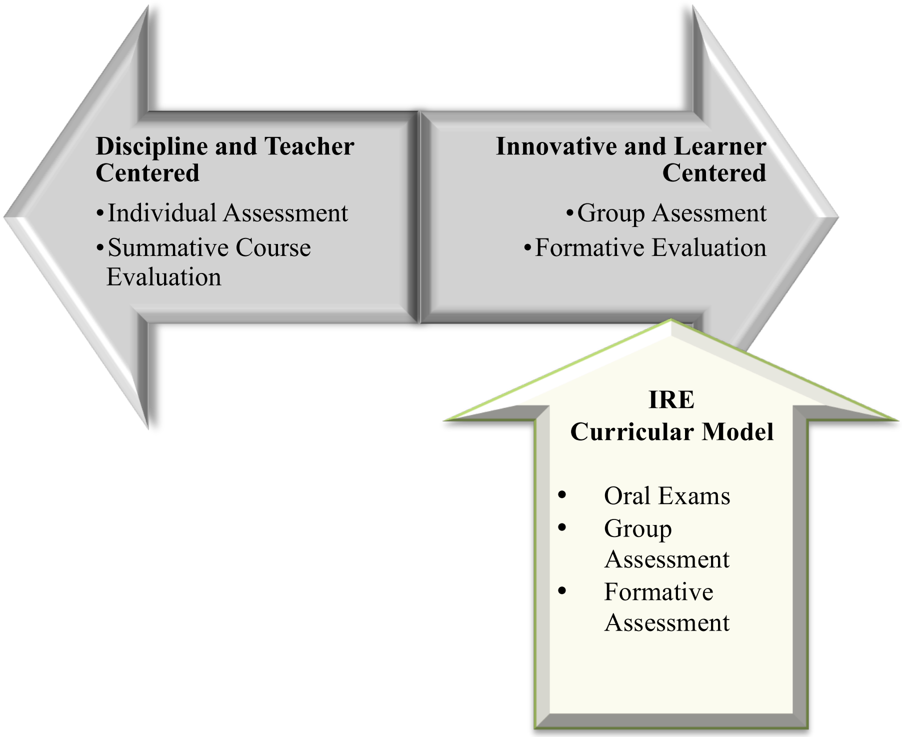

Figure 4.23. Assessment and evaluation spectrum

<u>Characteristics of IRE Model</u>

This section will specifically look at the IRE model approach to the assessment of the design, technical, and professional competencies. The learning activities that empower student to achieve growth in these competencies will be identified.

4.7.1. DESIGN ASSESSMENT

Formative assessment happens in the weekly informal design reviews. The facilitator provides developmental feedback on all aspects of the project execution and documentation. Project teams are evaluated based on the quality of the written design documents, the quality of their formal presentations, and the quality of the client deliverable(s). Panels of academic staff grade the documents and presentations to allow for consistent grading from team to team. In addition to the team grade, the project facilitator assigns an individual grade to each team member that reflects the level of contribution and professionalism he/she brought to the team. This aspect prevents "passengers" from achieving the same grade as their team when they may have contributed much less to the team deliverables.

4.7.2. TECHNICAL ASSESSMENT

Throughout a course, the faculty member provides low-stakes, formative feedback on the students' performance on daily assignments and conceptual understanding. The required components in a technical competency from a grading standpoint are these: DLA, technical evidence (notes, problem sets, concept maps, etc.), reflection journal, metacognitive memo, and an oral examination. The weighting of how much each of these components contributes toward the grade is a collaborative decision between the student and the instructor, made during the syllabus creation at the beginning of the block. Student input is given in an effort to provide them with ownership and control over their own learning. Grading is again of the five-point scale, from 1 (weak) to 5 (exemplary). The scale is applied to each deliverable. Table 4.9 shows an example of the rubric for the grading of a technical competency component.

The oral examination is a culminating one-on-one event at the end of the competency. Here the student defends their semester learning by answering questions regarding conceptual understanding, the integration of the new knowledge into the project or other DLA, and his metacognitive development. The oral exam process enables faculty members to pursue the boundaries of the students' knowledge and provides students practice in the important skill of verbalizing their understanding of technical knowledge. It drives towards demonstrating understanding rather than presenting memorized sets of information. Students have the opportunity to go down a wrong path, be questioned about the path, then recover and find the right path. When the Iron Range Engineering program was evaluated by an external agency, one of the greatest strengths identified was the oral exam process.

Table 4.9. Sample grading rubric for component of technical learning

	1 = Deficient	**2 = Weak**	**3 = Acceptable**	**4 = Desired**	**5 = Exemplary**
Describe concepts in an oral exam Weight _______	Does not identify key concepts even with much prompting, or explanations reveal serious misconceptions	Incompletely identifies key concepts with much prompting or explains them inadequately for proper understanding	Correctly identifies key concepts with minor prompting and reasonably describes them both verbally and symbolically	Correctly identifies key concepts without prompting and explains them well both verbally and symbolically	Promptly identifies key concepts and explains them contextually with skillful use of language and symbols

4.7.3. PROFESSIONAL ASSESSMENT

In each semester, the students evaluate their current level of professional performance, providing evidence of their judgment, set goals for improvement for the next semester, and write an action plan for achieving the goals. Table 4.10 shows the scale students use for these self-analyses.

Table 4.10. Professional development plan self-assessment scale

1 = Deficient	2 = Weak	3 = Acceptable	4 = Desired	5 = Exemplary
Shows little evidence of desired performance, clearly not acceptable for IRE graduates	Shows some but inadequate evidence of desired performance needed in IRE graduates	Shows moderate evidence of desired performance, minimally acceptable for IRE graduates	Shows strong evidence of desired performance, clearly meeting high expectations of IRE graduates	Shows unusually strong evidence of performance as a skilled professional, exceeding expectations of IRE graduates

Every semester there are several learning activities that empower students to achieve growth in each of these areas. These learning activities include the following: workshops by external experts, workshops by IRE academic staff, peer discussions, assigned readings, student presentations, videos, and personal reflection. In addition to learning opportunities, there are multiple methods for feedback on development. Examples include daily informal feedback from faculty to students, formal peer reviews, formal personnel evaluations from project facilitator to each team member at the end of the semester, and grading of various professional documentation submittals. The PDP is a comprehensive document; wherein, each semester the student adds her or his new assessments, goals, and action plans allowing for visible changes in development throughout the education.

4.8. CURRICULAR CLASSIFICATION OF THE IRE PBL MODEL

Beyond the classification of the curricular elements of the IRE PBL model with curricular elements of a PBL curriculum done in Sections 4.1 through 4.7 above, the analysis continues with a curricular classification through a synthesis of the curricular components of Section 2.2 from Biggs & Tang (2011), Jamison et al. (2014), Sheppard et al. (2009), Cowan (2006), Rompelman & de Graaff (2006), Kolmos and de Graaff (2014), and Beanland & Hadgraft (2013). From these works, a framework for classifying engineering curricula was developed. It consists of more than 25 questions, the answers to which create the picture of any engineering curriculum. Presented in this section will be the answers to these questions in regards analyzing to the Iron Range Engineering PBL curriculum. These questions provide another perspective to view the program.

Is there a higher emphasis on knowing, acting, or being? Or are they valued equally?

Iron Range Engineering students are encouraged to develop their own priority system with regard to knowing, acting, and being. The flexibility of project selection, team selection, and diverse choices in technical learning allow students choice. Those who may desire to go to graduate school have the opportunity to focus more deeply on KNOWING. Those whose passion is to use their engineering skills to impact the environment or societies can focus their choices towards BEING. However, the Iron Range Engineering program as a whole is focused on ACTING. The majority of students want to be practicing engineers in industry. The daily learning activities of students are focused on practicing engineering the way it will be done after graduation in industry.

Is the program scientific, entrepreneurial, or ecological? Or hybrid imagining?

As Jamison et al. (2014) describe these first three classifications, IRE would meet the classification of entrepreneurial. At IRE, a wider spectrum of skills and abilities are valued. In addition to technical acumen, abilities to design, communicate, lead, invent, and, overall, become a practicing professional are the attributes desired in the graduates. However, while the graduates tend toward careers in practice, the values of the program, as seen through the learning experiences of the students, lean towards the *hybrid imagining.* At IRE, we place equal emphases on "the scientific knowledge that is emphasized in the academic approach (in technical domain) and the practical skills that are emphasized in the market driven approach (in design and professional domains)", while emphasizing "social and cultural understanding" (in the professional domain). Examples of the emphases in the social and cultural domain can be seen in the development of several student projects focused on making lives better for people in need, in the substantial outreach volunteering that students do every semester, and in the learning activities focused around the student outcome of learning to succeed in a diverse environment.

What are the intended student learning outcomes?

There are 14 intended student outcomes described in Section 4.1.

To what level do they align with the Washington Accord? The IRE graduate outcomes meet all of the Washington Accord outcomes, with, perhaps, the exception that the WA places a higher emphasis on sustainability than do the IRE outcomes.

To what level is instruction aligned with outcomes? The instruction, as detailed in all syllabi, aligns extremely well with the outcomes. The assessments at the end of the courses, when grades are determined, are strictly aligned with the outcomes. The rubrics for the outcomes are the rubrics for the course grading.

To what level is enactment aligned with outcomes? While not equaling the high level at which the instructional design is aligned with the outcomes, the instruction enactment approaches that level. Differences between design and actual enactment can be seen when some instructors and students fall back towards a more lecture-focused, deliverable-focused mode of operation, rather than a learning-focused mode. This is normal, considering it is the fallback position that all the students and instructors knew before they came to IRE. The IRE continuous improvement model, described in Section 4.5, provides a mode for continual reflection and realignment with intended graduate outcomes.

Is identity-building an intended learning outcome? While not stated as a graduate outcome, the entire model is focused on the students believing they are engineers-in-training. The activities that build identity include these: the professional expectations of an IRE student (see Section 4.3); the ownership in decision making about which projects to choose, which teammates to select, when to take core competencies, and designing their own set of advanced technical competencies; professional interactions with real engineering clients while performing real engineering design work; and the overall expectation that the entire learning experience is preparing them for engineering practice, all lead students to developing their personal identity as engineers.

Are intended learning outcomes realized as actual student outcomes?

Both the individual student and the program, as a whole, explicitly focus on the graduate student outcomes. The outcomes are stated in each syllabus. There are posters throughout the physical spaces detailing the outcomes and performance indicators. Instructors emphasize, and students buy-in to the belief, that the outcomes are the expectations at graduation. Students create portfolios and professional development plans that track their growth in each outcome, during each of their four semesters.

Is there a continuous feedback system to ensure alignment of intended outcomes, instructional design, program enactment, and course enactment with actual student outcomes? Yes. Described in Section 4.5 is the IRE continuous improvement program. A component of this continuous improvement program is the collection of outcome portfolios from each graduating senior. The submittals for each outcome are sent to the external national advisory board of Froyd, Davis, Litzinger, Sheppard, and Jones. In pairs, they grade the outcomes, using the rubrics to determine to what level the IRE graduates are meeting the intended outcomes.

To what levels is the alignment achieved? The gap between desired level and actual achievement level continues to shrink each year. Early gaps were accentuated due to the poor ability of students to select and describe how their works met the outcomes, leaving the reviewers with a lower view of alignment than actual. Those issues have been overcome and gaps now are more realistic. IRE graduates tend to exceed expected levels in design and professional outcomes while being at, or slightly below, expected levels in technical outcomes.

Are the needs of the student addressed in the curriculum design and enactment?

To what level is motivation for student learning considered in the design and enactment of the curriculum? The IRE curriculum uses professional identity building, real engineering context, and substantial opportunities for students to have choices in their education, all in an effort to build motivation for student learning.

To what levels are students included in the decision making of learning activities? They give input to what kinds of projects will be sought in an upcoming semester. They choose the project they on which they will work. They select their teammates for design projects. They determine when they take which core technical courses. They have input into the design of the syllabus in every one of the 32 technical courses. They create the set of 16 advanced technical electives they will take, often choosing a specialty course that has not been offered in the program before. They are an integral part of the twice-yearly continuous improvement process for the program.

To what levels do faculty involve students in analyzing their progress in the achievement of their learning outcomes? Students track their progress of achievement in their professional outcomes through the continuous maintenance of the professional development plan. Each semester, students compile best practice submittals for the outcomes portfolio. The students analyze their own submittals against the rubrics to gauge their own achievement of the outcomes for all domains: technical, design, and professional.

Does the curriculum design/enactment align with exemplary practice?

To what level does the curriculum align with professional practice? All daily activities are designed to align with professional practice. This is exemplified by the students' professional development plans, requirements to live up to the professional expectations of an IRE student, periodic professional personnel evaluations, and interaction with real clients on real projects. All in an effort to develop their identity as a professional engineer.

Is PBL used? To what level? Yes. The entire curriculum is PBL.

To what level does the curriculum have and enact a professional spine? There are three credits of professionalism in each semester of the curriculum. Every week, students take part in professionalism workshops. They are made explicitly aware of the professional outcomes and track their own development in each outcome. The development of professional competencies is a weekly part of thee student conversation with their team facilitator.

Where does learning fall on the continuum of lecture/receiving to student-centered/active/constructive? All learning is designed to be student-centered/active/constructive. In practice, about 90% of learning is executed in this manner with 10% falling back towards lecture/receiving.

How is physical space allotted for student-centered learning? The physical layout (see Section 4.6) is designed exclusively for student-centered learning, with space dedicated to student project teams, full access to labs, and interaction between small groups of students and instructors.

How is assessment conducted? Formative/Summative, Individual/Group There is substantial formative assessment provided by academic staff to students and to students from their peers. Summative assessment comes at the end of each term when grades are assigned. Though, there is a formative atmosphere in which students can continue to improve their grade in any technical competency until graduation. The PDPs and personnel evaluations are formative in nature. Design teams receive formative feedback at each weekly design review and summative assessment at the end of each semester. Technical and professional assessment is primarily individual; whereas, design assessment is primarily group.

To what level are students treated as student engineers? In every sense of the meaning, IRE students are treated as student engineers rather than engineering students. They are given responsibilities and ownership at a level approximating those of new practicing engineers.

To what level do teaching faculty share and explicate a common view of professional practice? All faculty are involved in developing and executing the professionalism syllabus and expectations, as well as in performing formative and summative professionalism assessment. However, issues frequently arise wherein a small number of staff members exhibit behaviors that are counter to the expectations of students. In these instances, faculty credibility is damaged, as well as is the overall belief by students that the expectations are achievable. This is a substantial hurdle that the program fights to minimize.

To what level are students exposed to practicing professionals? At any one time, at least, two of the project facilitators are licensed professional engineers with substantial industry experience. The infusion of these professionals into the program, to interact with the students and academic staff, brings a higher level of understanding of professional practice. In addition, each team interacts frequently with their industry clients and several times per semester, practicing professionals are brought to campus to share their experiences.

Does academic staff receive training in facilitation? Yes. Aalborg University personnel have trained the IRE director in facilitation and, in turn, the director trains facilitators. In one instance, an Aalborg University member came to IRE to provide facilitation training to the facilitators. Each week, the facilitators meet for one hour to discuss topics and methods for facilitation that are appropriate to the week's activities.

To what level is reflection used in student learning? Are students given feedback on their reflective abilities? All students maintain a reflective learning journal in each of their technical competency learning experiences. These reflections are summarized in a metacognitive memo that students write at the mid-term and end of each semester. Technical instructors give feedback on reflection throughout the course of the competency. Reflection is central to the PDP process (see Section 4.4). At this point in time reflection is underutilized in the design learning.

Are academic staff trained in giving feedback on reflection? No. This is a missing component in the program, at this time, which should be addressed.

How are fundamental principles interconnected with each other and engineering practice? The central theme in each of the 32 technical competencies is the identification of the appropriate fundamental principles, understanding of the principles at a conceptual level, and connectivity of the principles to other principles, the semester design project, and the student's future engineering career. These connections take place during learning conversations, the creation of concept maps, the student's personnel journal reflections, and in oral exams.

Is a spiral model implemented for the learning of fundamental principles? The spiral model is central to all learning at Iron Range Engineering. Students are first exposed to the fundamental principles in their lower division courses before they get to IRE. Then, as they take core courses, these fundamental principles are revisited, interconnected, and connected to engineering practice. As the student's time at IRE continues, they spiral up as new projects or advanced technical competencies return to the use of the fundamental principles. For example, a typical student emphasizing in mechanical engineering will go through nearly 10 loops on the spiral for the fundamental principle of the conservation of energy. The students experience four loops of the professionalism and design spirals as they traverse their four semesters.

4.9. CONCLUSION

In Chapter 4, the Iron Range Engineering project-based learning model has been classified and analyzed with two different curricular models. The PBL curricular model, Figure 4.24, allows the IRE model to be compared to other models of PBL. The second curricular model, from Section 2.3, allows for a comparison of the IRE model to other models for engineering education.

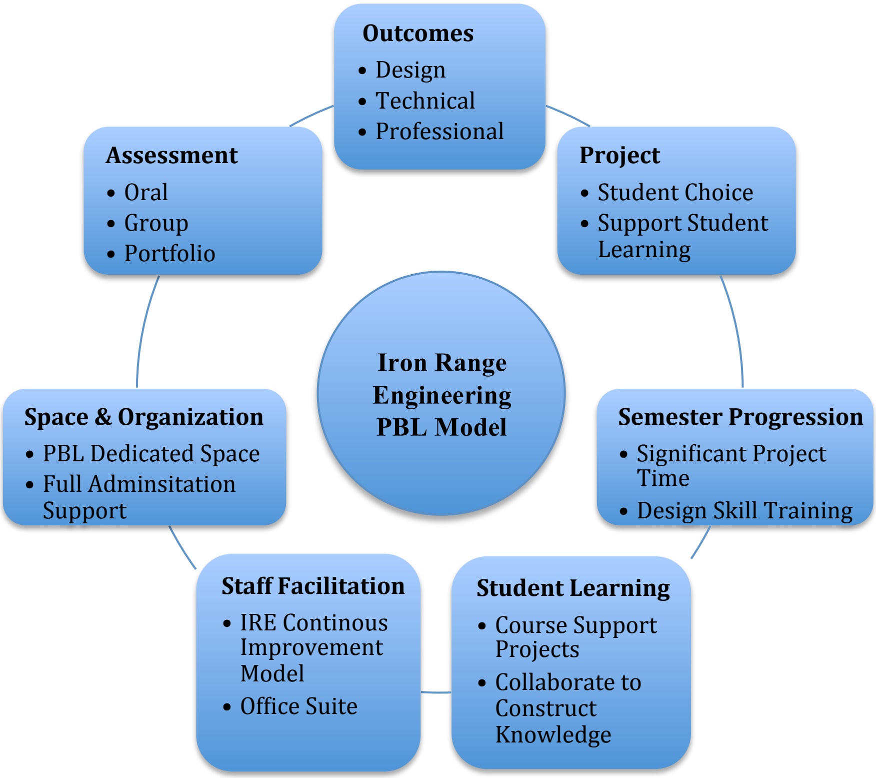

Figure 4.24. Iron Range Engineering PBL curricular model

Each spring, we spend six weeks of our time tapping maple trees, collecting sap, and boiling the sap down into syrup. During this process, it takes 40 liters of collected sap to harvest just one liter of syrup. As we look back over Chapter 4, we see a great deal of information (many liters of sap). All of this information is vital in describing and analyzing the IRE PBL curriculum. However, to get to a concise description of the curricular model, we use this analogy of seeking and yielding the 1-liter of syrup. It is in the distinguishing characteristics of the Iron Range Engineering PBL model.

The distinguishing characteristics can be described from the perspectives of the following: technical learning, design learning, professional learning, and the characteristics of the overall program.

Technical learning

Students learn the technical knowledge in "flipped-classroom" learning conversations rather than in lectures. In this way, the students watch a short video lecture (10-15 minutes) prior to class. Then in the class session, through questions and answers, conversation is held to assist the student develop her own conceptual model of the fundamental principles.

Each of the 32 one-credit technical competencies includes a process-learning DLA (deep learning activity). In these activities, students design experiments or some similar activity where they make a hypothesis, build experimental setups, collect data, analyze data, compare actual results to predicted results, and prepare a written report. Students complete eight DLAs per semester for each of their four semesters.

Oral exams are a hallmark of the program. Each student takes an oral exam where he describes his conceptual and problem-solving knowledge for each competency (eight per semester). Some oral exams are individual and some are in the form of small group exams.

Open-ended problem solving is practiced throughout each semester. In this activity, the students are given open engineering problems that require a broad set of inter-disciplinary knowledge to solve. They are given a final oral, one-hour exam at the end of each semester.

Design learning

Projects last one semester. Each project includes a team of 3-8 members, a team room, and a facilitator (either a practicing professional engineer or a staff member). Industry clients or student entrepreneurs propose the projects. The projects are authentic. In other words, staff members do not reformat the projects. Students interact directly with their client. The facilitator stands to the side and facilitates student learning rather than standing between the client and the group as a liaison. The teams create extensive written documentation and give six technical presentations. Three times per semester the team goes before a review panel to defend their work and work processes.

Professional Learning

Each semester the students undergo a wide variety of professional learning workshops on topics such as presenting, contemporary issues, technical writing, ethics, leadership, team conflict, inclusivity, learning about learning, and professional responsibility. They then put these professional skills to work in their learning environment, which is designed to model the environments from professional practice. In this environment they face high levels of expectation of professional responsibility.

Each student writes a professional development plan (PDP) wherein they write goals for development of their professional competence. They also write action plans as roadmaps for accomplishing the goals. Throughout the semester, they receive formative feedback from each other and academic staff on their performance in their goal areas. They reflect on their performance and developmental progress as the semester progresses and again at the end of the semester. The final reflection results in a set of new goals for the upcoming term.

The key to professional learning is a personal motivation whereby personal autonomy is valued and practiced as students achieve competence in a connected environment. A common statement at IRE is that “students create a trajectory of development to the engineer they want to become.” The resulting motivational levels are high and professional development is highly valued by the students and their community of learners.

Overall program distinguishing characteristics

Adapted from the Aalborg model is the concept of “team rooms” or “project rooms.” In this space, students have 24-hour access to an office they share with their project teammates. Through daily interactions, they organize their project, manage their interactions, and attempt to manage a collegial atmosphere. This space mimics engineering practice.

Reflection is embedded in the learning experience at a great depth. Students write three reflections per week on their daily experiences and development. Students write a technical competence related reflection each time they attend class. The PDP is a reflective document by nature. At the end of each half-semester, students write a reflective metacognitive memo wherein they analyze their learning processes and regulate their future learning. All members of the IRE community value reflection.

Continuous improvement is a way of life. The program embraces continuous improvement as a model for making substantial changes to the learning model each semester. The faculty members apply continuous improvement to their teaching.

Students apply continuous improvement to themselves as emerging professionals and self-directed learners. The community values the power of continuous improvement in engineering design and applies it every juncture within the learning model.

Finally, a last distinguishing characteristic is the act of being explicit. Much learning in their lives prior to entering the program was implicit. It was implicitly expected that if they passed a calculus class with an A grade, that the student would bring forward the relevant calculus knowledge to her future learning and engineering practice. The result of the implicit expectation is that the requisite knowledge was often not brought forward. At IRE, all expectations are explicit and reinforced through continuous expectation as well as continual feedback on development progress.

<u>Key Findings:</u> This set of distinguishing characteristics of the curriculum, developed from analyzing the IRE model, adds to the greater engineering education knowledge in how a curriculum can be developed to meet the calls for change. It also develops a greater understanding of student learning within this model of project-based learning. The results can be considered by engineering education and those individuals involved with curricular change decisions to better understand project-based learning, especially within the U.S. engineering educational context.

The distinguishing characteristic of being explicit, is in itself a key finding. The development of the curriculum identified the power potential that making learning outcomes explicitly has for empowering students in attaining learning and program outcomes. This commonly underutilized aspect has potential to be used in any curricular models within engineering education, not just PBL.

VOLUME 1 CONCLUSIONS

Volume 1 is a description and analysis of the Iron Range Engineering PBL program from four distinct perspectives: calls for change, theoretical, historical, and descriptive analysis of curriculum. First, the new model of PBL education was framed in terms of the calls for change in engineering education (Chapter 1) and then change theory, curricular theory, learning theory, and PBL theory (Chapter 2). Upon completion of the theoretical underpinning, the models of change theory were to be used to describe and analyze the historical development of the Iron Range Engineering program (Chapter 3). Finally, the PBL program was fully described and analyzed in terms of the curricular, learning, and PBL theories (Chapter 4).

The ultimate purpose of Volume 1 was to identify aspects of the change process and the developed curriculum that are of interest to the greater engineering community for meeting the calls for change and for developing a greater understanding of student learning within this model of project-based learning. It is intended to enable curriculum developers and decision makers in contemplating and implementing a curricular change process. In addition, Volume 1 provides an extensive background and develops the focus for our individual Volume 2 editions where we design research studies on the self-directed learning (Ulseth) and professional competency development (Johnson) of the students in the IRE program.

Summary of work completed

First, we highlighted the calls for change in engineering education (Chapter 1). These calls aim for a better alignment between the knowledge and skills desired in engineering graduates and the learning activities and processes in the engineering curricula. Many of these calls served as an impetus for the start of the IRE program. In particular, Sheppard et al., (2009) served as both impetus and guide when the program began in early 2010.

Next, was the process of creating theoretical frameworks. In regards to change, we developed a case to use Froyd's organizational change model and the dual-layer curricular change model from Kolmos and de Graaff (Chapter 2.1). These two models served as the structure in providing the historical context of the Iron Range program.

An analysis of curricular theory (Chapter 2.2) resulted in the development of a framework consisting of more than 30 questions that, when answered, characterize a curriculum in multiple dimensions. The many sub-questions fall under the following main questions:

- Is there a higher emphasis on knowing, acting, or being? Or are they valued equally?
- Is the program scientific, entrepreneurial, or ecological? Or hybrid imagining?
- What are the intended student learning outcomes?
- Are intended learning outcomes realized as actual student outcomes?
- Are the needs of the student addressed in the curriculum design and enactment?
- Does the curriculum design/enactment align with exemplary practice?

The answers to all of these questions give a program a unique "finger print." The ability to describe a curriculum to this level of detail enables curriculum developers the ability to understand the attributes of the curricula in ways that would allow them to contemplate its potential values for adaptation. The ultimate goal of the section was to use this framework to analyze the Iron Range Engineering program in these dimensions.

In learning theory (Chapter 2.3), we started by describing Illeris' model (2007) and then used Bransford (2006; 2000) and Sawyer to give validation to Illeris' model. We then, presented a discussion on constructivism as the primary theory of learning on which modern views of best practice are built, and included the constructivist-based American Psychological Association's learner-centered psychological principles. We followed up with descriptions of the following relevant components of learning and learning environments: development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity. Ultimately, we presented a synthesis of the work in order to build a framework to analyze the Iron Range Engineering model in Chapter 4.

The final theoretical discussion and framing took place on PBL (Chapter 2.4). We embraced the curriculum model that is based on the PBL learning principles and on the curriculum theories of alignment and social construction. The PBL curriculum model is linked to the PBL principles. The seven elements are as follows:

- objectives and outcomes,
- types of problems, projects, and lectures
- progression, size and duration,
- students' learning,
- academic staff and facilitation
- space and organization, and,
- assessment and evaluation" (Kolmos & Graaff, 2014)

We identified that each of the elements of this PBL curricular model has a broad spectrum from a teacher-controlled on the one side to an innovation and learner-centered approach on the other side. Between each of the ends of this spectrum are several degrees of varying, mixed approaches that can be applied in the development of a PBL curriculum. We then created a visual model for placing the IRE PBL curriculum on the continuums for each of the elements with the intent of applying the model in future chapters.

The history of the development and implementation of the Iron Range Engineering program was told in-depth (Chapter 3). The framework for the history came from applying both of the change models identified in Section 2.1. The data for the story came from a wide variety of conference papers, magazine articles, and newspaper articles published on the IRE program over the many years that development and implementation took place. Early beginnings of the program came out of the successes at Itasca Community College engineering program in Grand Rapids, Minnesota. The history starts with a detailed description of that program showing how its elements would serve as the seeds that would grow into many of the elements of IRE. The history further details how the needs of the region resulted in the program's funding. The influences of a national advisory board and the Aalborg University model were included. Finally, the history is told through the program's ABET accreditation and up to the present day.

The build up in Volume 1 was towards a full description of the IRE model of project-based learning (Chapter 4). In great detail, the program was described and analyzed from many perspectives. Using the elements of PBL curriculum identified in Section 2.4, the information was organized into sections for: objectives/outcomes, problems/projects, progression/size/duration, student learning, academic staff/facilitation, space/organization, and assessment/evaluation. The curriculum focuses of professionalism, design, and technical learning were described. Finally, the frameworks for classifying developed in Chapter 2 were applied to the program to show its attributes at levels of fine detail.

Findings

The analysis of the IRE PBL model identified key findings from the change process and the developed curriculum that are of interest to the greater engineering education community:

- the successful curricular change process,
- the distinguishing curricular aspects of the new PBL curriculum,
- the explicit focus on student attainment of design, technical, and professional competencies,
- and the two taxonomies for analyzing a PBL curriculum; the arrow spectrums from the PBL elements and the 30 curricular questions from the learning theory.

In this section, the findings will be analyzed in terms of the potential for further study.

Successful Curricular Change Process

The history of the Iron Range Engineering is a story of a successful curricular change process as viewed through the perspectives of organizational change and management of educational change. It is bottom-up in its creation as a new entity; its ideation, development, and continuous improvement being driven by faculty. It is top-down in its creation as a department in the College of Science Engineering and Technology at Minnesota State University, Mankato and support by top-level leadership at the institutions involved. Success of the start-up is evidenced by the continued existence and current vibrancy of the program. Section 2.2 of this thesis identifies and describes essential attributes for change to succeed:

- Need for both external and internal drivers
- Leadership team
- Vision casting
- Empowering people to act
- Formative evaluation

These attributes are critical elements in the change that was accomplished and can be used in consideration of change within other engineering programs in the U.S and add to the knowledge of change in engineering education.

In regards to further study, this topic has been analyzed extensively in Volume 1 and through external research by a team who has studied the impediments to change. This work identified the additional opportunities for study of each of these elements in finer detail. By characterizing the nature of each element in studying the implementation at a deeper level, more knowledge of the process could be gained and shared.

Distinguishing curricular aspects of the new PBL curriculum

A description of the new PBL curriculum is contained in its positioning within the curricular elements of PBL and through the set of distinguishing curricular elements developed from analyzing the way in which the IRE model meets the calls for change. The distinguishing curricular elements are grouped within the design, technical, and professional competencies:

- Technical Learning
    - Flipped classroom – Learning Conversations
    - Deep learning activities in each course
    - Oral exams

    - Open-ended problem solving
- Design Learning
    - One-semester projects
    - 3-8 person teams
    - Facilitation
    - Authentic industry problems
    - 3 design panel reviews per semester
- Professional Learning
    - Professional Development Plan
    - Personal Trajectory in Professional Development
    - Engineering Practice Environment
    - Professional Expectations
- Overall Program
    - Team Rooms
    - Reflection throughout
    - Continuous improvement
    - Explicitness

In regards to further study, the distinguishing curricular elements within the design, technical, and professional competencies have been described in terms of approach, how they are underpinned by theory, and the potential for success. The student development for and attainment of the competencies within these categories for this PBL program needs further study. They could be studied as a whole or for each individual category.

Explicit focus on student attainment of design, technical, and professional competencies

One additional distinguishing characteristic is the act of being explicit. Much learning in the student lives, prior to entering the program, was implicit. The result of the implicit expectation is that the requisite knowledge was often not brought forward. At IRE, all expectations are explicit and reinforced through continuous expectation as well as continual feedback on development progress.

In regards to further study, the act of making student attainment of competencies explicit is of value further study. This aspect of the curriculum has potential for implementation in a wide variety of engineering education learning models to improve student learning.

Two taxonomies for analyzing a PBL curriculum

The study of the IRE PBL program led to the development and analysis of the program with two taxonomies for characterizing a PBL curriculum. The arrow spectrums from the PBL elements and the 30 curricular questions from the learning theory allow for various PBL curriculums to be analyzed and positioned compared to one another. The intent is to not rank models in comparison to one another, but to understand the different curriculums as PBL is applied in different social and education contexts. As PBL is implemented more widely, it provides "language" for comparative discussion as individuals involved with curricular change seek understanding.

In regards to further study, the use of these taxonomies on different models and the subsequent continuous improvement activities are needed. These taxonomies are at the initial version stage and further study and development are needed for them to fully benefit engineering education.

Closing comments

This completes Volume 1 of these theses. It is a descriptive analysis of the Iron Range Engineering PBL program from four distinct perspectives. Key findings, of interest to the greater engineering education community, from the change process and the development of the curriculum were identified along with potential topics for further study.

The shared work ends at this juncture. The act of completing this volume feels like an open circle has finally been closed. For over 10 years, we have been developing and implementing the IRE PBL model. For this entire time, the focus was on the next iteration of continuous improvement to implement. The need to apply theoretical constructs to our work was never important enough to do. We often chide our students for performing "garage engineering" where they complete their designs simply from intuition and innate ability, never taking the time to relate their work to the fundamental principles of engineering. We preach that the power of engineering emerges when their abilities are bolstered with the science. We designed and implemented the IRE model working as "practitioners" utilizing "best practices" and intuitively developing innovative approaches without fully understanding the theory behind them.

That is no longer. This volume has resulted in completing that work of developing the theoretical underpinnings of the IRE PBL curriculum. So many things that worked or didn't work now make sense. Our ability to understand and disseminate the work is now much improved. Each of us now moves forward with the contextual background from this extensive work, as researchers, into our individual studies in Volume 2.

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VOLUME 2 INTRODUCTION

In Volume 1, the Iron Range Engineering PBL program was described and analyzed from four distinct perspectives: calls for change, theoretical, historical, and descriptive analysis of curriculum. It provides the background and historical perspective for Volume 2.

One of the findings identified in Volume 1 is the distinguishing curricular aspect of *Professional Learning*. It relates to the professional competency development gap in engineering education. An additional distinguishing characteristic is the act of being explicit. Combining these two, the act of making student attainment of professional competencies explicit is worth further study in Volume 2.

The intent of Volume 2 is to provide an understanding of how PBL can address the professional competency development needs. Specifically, the study is intended to provide engineering education decision-makers with descriptive data to understand how the PBL curriculum influences the student development of professional competencies. The results will identify which aspects of PBL influence transcend across all PBL curriculums and which practices are specific to the IRE program. They are intended for consideration to engineering education decision-makers for inclusion in continuous improvement and curricular development work at their institutions.

Volume 2 begins with a theoretical perspective of professional competencies and an analysis of the current state of professional competency development in engineering education. The PBL curricular model will be further developed, along with what is best understood regarding professional competency development, creating a cyclical process of exploration and reflection that develops the student professional identity and their performance ability of professional competencies.

A mixed-methods study will be conducted to look at the professional competency development as evaluated through both a quantitative analysis and then through a qualitative analysis. The study will seek to answer the primary research question, "In what ways does the project-based learning (PBL) curriculum influence the development of professional competencies?"

The quantitative study looks at both the internal (individual) interactions and external (team) interactions from Illeris's model for evaluating the student development. It will compare the development of students in the IRE PBL curriculum pre- and post- as well as comparing to the pre- to post- difference of the students experiencing a traditional upper-division engineering program. The qualitative study will identify how the PBL students experienced the development of the professional competencies through the formation of their professional identity. It will see how students identify the elements of the PBL curriculum as part of this development.

Volume 2 concludes with combining the quantitative and qualitative results to develop an understanding of how the PBL curriculum influences the student development of the performance of professional competencies. How this work contributes to the state of the art for engineering education will also be identified.

CHAPTER 5. DEVELOPMENT OF PROFESSIONAL COMPETENCE

As identified in Chapter 2, a gap exists between engineering education and the current and future needs of the engineering profession. This global situation has led to international calls for transformative change in engineering education. A significant step by the international community to eliminate the gap between educational and industry expectations for engineering students commenced in 1989 with the professional organizations and institutions from Australia, Canada, Ireland, New Zealand, United Kingdom, and the United States forming what became the Washington Accord. They were later joined by several countries from around the world (Beanland & Hadgraft, 2013). It sought to establish standards for professional competencies and develop desired attributes for engineering students graduating from an accredited institution. Specifically, it created a competency focus for engineering education and broadened the focus of engineering education to include preparation for professional practice. Lemaitre, Prat, Graaff, and Bot (2006) confirm that the preparation "of students for professional competence has always been the ultimate goal of engineering curricula."

In 1996, ABET, the non-governmental accrediting body for engineering education in the U.S., introduced a new set of engineering accreditation criteria, ABET Engineering Criteria 2000 (EC2000). Of greatest significance to changing engineering education was the General Criterion 3 student outcomes, also known as the ABET Criteria. This set of outcomes reflected a movement in the U.S. towards a focus on the student development of their professional competencies. Similar movements were taking place in other countries around the world. In the United Kingdom, the application of the Washington Accord was through the Engineering Council UK. In Australia, Engineers Australia established the competency standards.

Despite this initial movement and interest by universities and engineering faculty throughout the U.S., engineering education still does not provide graduates with the competencies identified as needed by industry (Walther & Radcliffe, 2007). In the *Educating Engineers: Designing for the Future of the Field* (Sheppard, Macatangay, Colby, & Sullivan, 2009) study of engineering programs at several U.S. institutions. Sheppard et al. identified that the engineering education system had not changed much in regards to the curriculum meeting the professional competency needs of the profession. They found that the engineering curricula were still heavily biased towards analysis to the detriment of professional competencies development, as well as other areas of engineering. Most educational experiences were still based on an assumption that the development of professional competencies can occur in a set of discrete finite episodes with a beginning and an end (Wenger, 1998). This is despite the fact that students and employers, alike, expect a higher degree of synergy between what is learned in the classroom and what is needed in the field (Passow, 2012).

Rompelman and de Graaff (2006), when they proposed that engineering education curriculum should be developed from a systems approach, highlighted the Van der Vleuten observation that university professors appear to use intuition as their approach to teaching methodologies instead of using a scientific approach. In the systems approach, they propose that an educational process transforms students from their initial attributes to graduate attributes as they complete the education process. The proposed premise is that the learning process is one where the learner "constructs knowledge on the basis of prior knowledge and additionally acquired information." This process is based on a constructivism perspective (Jonassen, Peck, & Wilson, 1999).

In this chapter, a learning-process approach will be advanced that, within the IRE project-based learning curriculum, develops the professional competencies desired from engineering education in its graduates. It means shifting the student development focus to go beyond just technical competencies to developing the whole engineer (Goldberg & Somerville, 2014). Goldberg and Somerville (2014) state that "helping students develop as complete human beings, with whole minds and bodies engaged in learning, who are practiced in understating in a variety of ways, is the education mandate of our times." Not only will this better develop engineering students to meet the needs of their profession and society, but also it should increase the appeal of engineering education to a broader spectrum of student intelligences and thus increase the pool and the diversity of new engineers. (Goldberg & Somerville, 2014).

The first step in this study is defining professional competencies and then an examination of how engineering education is currently developing these professional competencies. Next, the chapter will explore the role of professional identity development for professional competencies. This process is followed by a review of the literature regarding effective curricular elements for developing professional identity and competencies. Then a learning process will be described and proposed within the Iron Range Engineering PBL curriculum model for developing professional competencies.

5.1. PROFESSIONAL COMPETENCIES

Cajander, Daniels, and Von Konsky (2011), in their study of professional competency development in engineering education, identified that the lack of a clear definition for the professional competencies makes it difficult to set development goals which move past the program level and into the individual course level where student learning takes place. Creating the definition for competencies is a critical part of developing the proposed learning process within this PBL curriculum.

A review of the literature regarding definitions of professional competencies yields several descriptions. These descriptions focus on not only the individual's acquisition of knowledge and skills, but also on the individual's ability to utilize the knowledge and skills in complex real-world situations and systems (Cajander et al., 2011; Heywood, 2005; Hutcheson, 1997; Kolmos, 2006; Lucena, Downey, Jesiek, & Elber, 2008; Mentkowski et al., 2000).

Passow (2012) defines professional competency as "the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life." Spencer and Spencer (1993) conceptualize competencies as an iceberg where the visible tip above the water line represents the visible skills and knowledge domain of students. Student traits, self-conception, and motives are the base of the iceberg and are the foundation of human competence. De Graaff and Ravesteijn (2001) refer to competencies as an emphasis on "potential rather than a specific outcome, a process rather than a defined product."

For purposes of this study, professional competency will be defined as the potential that students have to use professional knowledge and skills to perform in the complexity of a real-life engineering situation. The student's self-conception and motives are considered an important foundation for these competencies and will be part of the student identity development.

The professional competencies of focus for this study will be the ABET student outcomes in Criteria 3. The criteria of specific focus are: 1) an ability to function on multi-disciplinary teams (3.d); 2) an understanding of professional and ethical responsibility (3.f); and 3) an ability to communicate effectively (3.g). These three competencies represent the professional competencies as compared to the other ABET criteria, which are more technical in nature. These three competencies do exclude the life-long learning competency, which is the focus of my colleague Ron Ulseth's parallel thesis topic on the new PBL curriculum.

Passow (2012) identified these three afore-mentioned criteria in a study of the ABET competencies, as those found most important by engineers in the workplace. The same three competencies were also the characteristics identified by Katz (1993) as the missing skills of engineers as they transitioned from being an engineering student to being an engineer in the professional work environment.

A curriculum seeking to address the gap between engineering education and the current and future needs of both the profession and society will effectively develop these competencies in students. Before proposing such a curricular approach, the current state of how these competencies are developed in the U.S. educational system will be evaluated.

5.2. CURRENT STATE OF PROFESSIONAL COMPETENCY DEVELOPMENT

Shuman, Besterfield - Sacre, and McGourty (2005) identify that a variety of practices are being employed to develop students' competency in the U.S. engineering education system for each of the ABET professional outcomes. Although no single method is highlighted for its effectiveness, Shuman et al. identify that the traditional lecture format is not the most effective method for teaching the ABET professional competencies and that a modern engineering education should focus on active and cooperative learning approaches. Webster-Wright (2009) also identifies that the continued focus on delivering content versus enhancing learning for development of students acts as a barrier to the student development of the professional competencies.

Loui (2005), in a study of how engineering students conceive themselves as professionals, found that students learned more about professional competency from relatives and co-workers than they did from their educational course work. He proposed that engineering education should have a focus of "socializing students to become professional engineers." Clearly there is significant potential to improve professional competency development in the U.S. engineering system.

The 2011 series of articles in the Journal of Engineering Education supports this consensus regarding the ineffectiveness of traditional educational models in engineering education for meeting the professional needs of engineering education. These articles focus on the state of engineering education and promising practices for the future (Lohmann, 2011). This series is part of JEE's commemoration of its 100th anniversary.

In this series, Walther, Kellam, Sochacka, and Radcliffe (2011) focused on an investigation of the professional formation of engineering students to determine what influences contributed to their formation and what were the results. The study identified five influences. The first, the 1) logical planned learning activities of engineering curriculum, did have some influence on student professional development. These activities are the lecture, group project, research projects, writing assignments, and homework assignments that are part of most engineering programs. There were four additional influences identified in the study:

> 2) The Learning Environment, the culture developed in the programs, specifically what was valued in the assessment process and what was emphasized in the curriculum, creates a learning environment that influences student professional competency development;
>
> 3) Student Disposition, the student's innate traits and personality in combination with his family and educational background, influences his ability and value placed on professional competencies. Loui identified this as the primary influence of professional competence development;
>
> 4) Extra-Curricular Elements, the activities outside of family and the educational setting, have an influence on the student; and
>
> 5) Meta-Influences, the environment developed within an academic program, can have a significant influence on the socialization of students, which Loui emphasizes.

These influences on the student professional competency development resulted in what Walther et al. describes as three different types of outcomes for engineering students in today's education model. First, the "Intentional Learning Outcomes" are the planned positive outcomes of the engineering curriculum. Additionally, the study identified both "Accidental Competencies" and "Accidental Incompetencies." Accidental competencies are the unplanned positive outcomes of the student experience that resulted primarily from the four additional influences. The accidental incompetencies are the negative competencies that are an unintended outcome of all five influences.

Walther's work identifies the complexity of the individual student's development of professional competencies. Results of the study indicate the formation of the competencies is indeed the result of a complex social learning process. This directly contrasts the inherent rigid structure of most engineering education institutions.

Connecting what Walther identified in his study to Illeris's (2002) theoretical work on the dimensions of learning, described in Chapter 2, the learning activities and student disposition create the internal interaction process for the content and incentive dimensions of learning. The content and incentive dimensions are the focus of most engineering curriculums and are intended to influence the intentional learning outcomes of the contextual model. The issue that Walther identifies in his work is that this **"is"** the emphasis of most engineering programs with little regard to the other influences.

Illeris's third dimension, the environment dimension, does consider the external interactions that take place during the learning process between the learner and the learning environment. The external interactions are created by the remaining three influences, learning environment, extra-curricular activities, and meta-influences of the contextual model of competence formation. These interactions directly influence the formation of accidental competencies and incompetencies.

In the development of the new PBL curriculum, all three of Illeris's dimensions are explicit intended outcomes of the curricular development. The area to which this research work can contribute the most is increasing the understanding of the role of the environment dimension in the development of professional competencies.

Johri and Olds (2011), in their work on bridging engineering education research and the learning sciences, also identify the potential for a focus on the external dimension for improving engineering education and furthering the understanding of learning in engineering education. They specifically emphasize: the physical and social aspects of context in learning; the socially and culturally negotiated nature of learning; and that all student learning takes place in a social and material context.

In summary of the reflection on the current professional competency development in the U.S. engineering education system, a simple focus on designing just the curriculum to develop professional competencies is not enough. The development process is more complex and requires a curriculum that recognizes that students participate in a community of learners, and therefore incorporates the social external interaction dimension as part of the program design.

Tonso (2006) identifies two key aspects of this development process: first, the compliance with the standards of the profession (competency expectations) and then the identification with the profession (belief of being an engineer). It is through identity development that an individual develops professional competency. Tonso (2006a, p.273) states: "identity production was a complicated process that bound up *thinking about oneself as an engineer, performing as an engineer self and ultimately being thought of as an engineer."* Eckert (1989) also found identity development to have a significant role in an individual's learning trajectory. The next section will review the literature in regards to the identity development process.

5.3. PROFESSIONAL COMPETENCIES THROUGH PROFESSIONAL IDENTITY

If we look at the process of developing professional competencies, it is about developing the competencies and ability to be successful in the professional workplace. Goldberg and Somerville's emphasis on the whole engineer and the Spencer and Spencer (1993) iceberg conceptualizes the need for the entire person to fully develop the professional competencies. This conceptualization makes it hard to understand a curricular model that focuses on just the competencies without focusing on the development of the entire person through professional identity.

The German concept of Bildung reflects the development of the whole individual beyond just the technical knowledge and skills (Christensen, Henriksen, & Kolmos, 2006). This development of Bildung goes beyond academic disciplines (Borrego & Bernhard, 2011) and is both the *process* of the initiation of the individual into the culture and tradition of engineering to develop talents to the fullest potential and also the *product* of the process (Henriksen, 2006). Du (2006) connects Bildung through a sociocultural perspective to the development of identity. The process of learning professional competencies is an "identity construction process as well as a self-transformation process (Du, 2006)."

Dehing, Jochems, and Baartman (2013) stated that the process of professional identity formation should be the aim of curriculum and that the "curriculum process has to be redesigned. Recent studies suggest that a better connection between theory and practice within the context of the engineering profession and the student identification with the formation of professional identity are important drivers for change." They cite several recent studies that suggest this (Geurts & Meijers, 2004; Pierrakos, Beam, Constantz, Johri, & Anderson, 2009; Sheppard et al., 2009; Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008; Sullivan, 2004).

Hult, Abrandt, Dahlgren, Dahlgren, Hård af Segerstad, and Jeffery (2003) in their comparative study of students in psychology, political science, and mechanical engineering programs found that the engineering students expressed doubts as to their professional identities, these doubts affected their ability to find a meaningful relationship between their studies and its value to their future careers. Ibarra and Barbulescu (2010) identify the development of professional identity as an important factor in the student adaption to the professional workplace. Loui, as well as Johri and Olds, identified the potential of professional identity development for meeting the needs of the engineering profession (Johri & Olds, 2011; Loui, 2005). Research by Wasilewski (2015) indicates a possible relationship between professional identity and the persistence in engineering careers.

Professional identity is more than just knowing professional competencies; it is the ability to create a narrative that the individuals continue to construct, use, and refine (Roth et al., 2004) in their educational and professional careers as they position themselves in relation to the profession (Stevens et al., 2008). The identity is the base from which students act out professional competencies.

There are several other definitions in the literature for professional identity. According to Beam, Pierrakos, Constantz, Johri, and Anderson (2009), professional identity is how closely an individual relates to a particular field, profession, or occupation. Sheppard et al. (2009) describes it regarding standards of the professional community “to serve the public with specialized knowledge and skills through commitment to the field’s public purposes and ethical standards.” Eliot and Turns (2011) define it as the “personal identification with the duties, responsibilities, and knowledge associated with a professional role.” Ibarra (1999) defines it as “the relatively stable and enduring constellation of attributes, beliefs, values, motives, and experiences in terms of which people define themselves in a professional role.”

Dehing et al. places these various definitions of professional identity into two groups. One group focuses on the social dimension of identity building, the Beam & Pierrakos, Stevens et al., and Ibarra definitions. This grouping does not include the more individual process of identity development as the second group does. The second group Sheppard et al. (2009) and Sullivan (2004) (among others) recognizes the normative standards of the profession as individuals both position themselves and allow others to position them relative to the normative standards (Stevens et al., 2008). The study conducted by Dehning et al. found support for this position that the professional identity development process has both a *social* and *individual* dimension.

These two dimensions correlate back to Illeris’s (2002) dimensions of learning. The individual dimension correlates back to the internal interactions of Illeris’s content and incentive dimensions. The social dimension correlates back to the external interactions of Illeris’s social dimension. Eliot and Turns (2011) propose that professional identity is developed through a social process where students are connecting expectations with their own needs, wants, and attitudes. Wenger (1998) places the identity development process in the context of learning in a community of practice.

If the professional competencies are the visible skills and student knowledge domain of Spencer and Spencer (1993) iceberg analogy, the student professional identity is the less visible base of the iceberg (student traits, self-conception, and motives). The next section will focus on the curricular elements for developing the student professional identity and visible professional competencies.

5.4. CURRICULAR ELEMENTS FOR DEVELOPMENT OF PROFESSIONAL IDENTITY AND COMPETENCIES

Four core curricular foci emerged through a literature review of curricular approaches for professional competency development, which recognize the role of professional identity development. The review focused on the design of a learning environment that recognizes both the individual and social dimensions in the professional identity development as underpinned by Illeris’s model.

The first curricular focus identified is the *competency outcome-based* nature necessary for professional development. This agrees with the professional competency focus from the Washington Accord. It also provides a normative standard by which students may position themselves. The second curricular focus is the *role and value acquisition* process, which provides students with both the individual and social dimensions for the development of their professional identities as engineers. This relates to the development of the whole student or Bildung. Third, a *Project-Based Learning* (*PBL)* curriculum is the key aspect of supporting the first two foci through the learning of professional competencies and development of professional identity embedded in professional practice. The fourth is the role of student reflection in the development of professional identity and professional competencies.

The literature review focused on the design of learning environments developed in Chapter 2 and was viewed through the lens of Bransford, Brown, and Cocking (2000) concepts for developing the foundation of learning systems: *development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity*.

5.4.1. COMPETENCY OUTCOME-BASED EDUCATION

> "When there is alignment between what we want, how we teach and how we assess, teaching is likely to be much more effective than when it is not" – (Biggs & Tang, 2011).

Biggs and Tang (2011) identify, that for alignment to occur, there needs to be clear communication of what the objectives of the learning are to both the student and the instructor. These objectives form the basis for an outcome-based educational approach, a world-wide practice with a long history (Dahl, 2008).

Harden, Crosby, Davis, and Friedman (1999) in their study of outcome-based education in the medical profession identified the importance of a "clear and public statement of the learning outcomes" for an educational program. They note that outcomes exist in an educational program whether by design or not. This is evident in engineering education through the identification of the accidental competencies and incompetencies by Walther et al. (2011), as described earlier.

Harden et al. (1999) create an analogy between the competency outcomes of an education model and the plan an architect develops for a building. The plan not only represents what has been proposed and agreed to, but it also allows all interested external parties to see if it complies with governmental regulations, how it will impact the environment around it, and provides additional opportunities for change negotiations. To internal partners, it communicates what materials are required, allows for planning of methods to construct, and is a means with which to compare if the final product meets the original intent. So exists the need for a new engineering program to be clear about its intent to develop the professional competencies as an outcome for the students and determine if the model delivers that intent. These competencies communicate to external partners and stakeholders the intended developmental focus of the program. Internally, these competencies guide the curriculum development and guide the learning focus of students.

Spady (1988) defines outcome-based education as "a way of designing, developing, delivering, and documenting instruction regarding its intended goals and outcomes." He suggests that the "exit outcomes are a critical factor in designing the curriculum" and that you "develop the curriculum from the outcomes you want students to demonstrate, rather than writing objectives for the curriculum you already have." In developing the new PBL program, the ABET criteria [an ability to function on multi-disciplinary teams (3.d); an understanding of professional and ethical responsibility (3.f); and an ability to communicate effectively (3.g)], were identified as the intended and desired competency outcomes of the program and were explicitly communicated to program leaders, advisory board, faculty, students, and the public who were involved with the program development. These three outcomes, their performance indicators, and grading rubrics are included in Appendix E.

Connecting back to the Washington Accord, used by ABET and other national accrediting bodies throughout the international community, it supports the adopting of an outcomes–based approach to curriculum development. "The fundamental purpose of engineering education is to build a knowledge base and attributes to enable the graduate to continue learning and to proceed to formative development that will *develop the competencies required for independent practice*" (washingtonaccord.org, 2015). As with any educational approach, an outcome-based educational approach needs to be incorporated in a way that supports the educational model (Steiner ‐ Khamsi, 2006). In this instance, the learning outcomes will support the identity formation through a role and value acquisition process.

5.4.2. ROLE AND VALUE ACQUISITION

If we think of education as both an individual and social process for students becoming professional engineers, the standard four-stage model of role acquisition can be used to develop a curriculum to create this process of acquiring the value for the professional competencies (Loui, 2005). Thornton and Nardi (1975) proposed that the identification with a professional role is a developmental process in which the student goes from having an idealized perception of the professional role to a more personalized role that aligns with his own values and goals. The term "role acquisition" is used to describe the process of developing a professional identity. Thorton and Nardi define the role acquisition as a four-stage process:

1. Anticipatory Stage

Individuals start with a highly idealized understanding of the role of the professional. Individuals at this point have only a very generalized and usually a very stereotyped concept of the professional role they are entering. This concept is not generally based on the normative standards or professional competency expectations of the professions. Student expectations are often based on the perspective of members of the society as a whole. This leads to individuals often having an incomplete understanding of the professional role for the career they are entering. "Social and psychological adjustment" to the professional identity is initiated in this beginning stage. This initial adjustment is only of value to the extent to which the individual's understanding of the profession is accurate. Inaccuracies at this point can be detrimental to the individual's development.

Engineering students often enter programs with idealized knowledge of the daily work life of engineers (Eliot & Turns, 2011). Most often, student professional identity is formed by interactions with their relatives and friends (Loui, 2005). The degree of the accuracy sets the initial trajectory of the student's professional role development.

2. Formal Stage

Individuals undergo a formal learning experience with the purpose of learning the duties, responsibilities, and knowledge for a professional role. There is a shift from viewing the role from the outside to experiencing it as an "incumbent." Understanding and expectations for the role now come from the members of the role set, both peers and individuals in reciprocal roles. They also come from the individuals themselves as they experience responses from others in regards to their professional performance. Expectations at this point are generally formal and explicitly stated. The individual often views them as "a set of must behaviors." These formalized expectations focus more on the "behaviors, knowledge, and skills" of the individuals in the role acquisition than the actual attitudes held by the individual. This stage appears to most as a process of the individual conforming to the professional role.

Engineering education primarily focuses on this stage of role acquisition through formal and traditional educational methods. It is the intentional learning outcomes of the Walther, et. al., Contextual Model of Competence Formation. This approach alone is generally identified as inadequate in preparing students for their professional engineering roles (Weidman, Twale, & Stein, 2001).

3. Informal Stage

Individuals encounter the unofficial or informal expectations associated with the professional role. These may align or contradict the formal expectations. In contrast to the formal stage, expectations for the role are transmitted through informal interactions with both colleagues and individuals in reciprocal roles. Within this stage, peers and colleagues have the greatest credibility. Expectations become more of the "mays" of the profession than the "musts" found in the formal stage. These expectations tend to be more "implicit and refer to the attitudinal and cognitive features of role performance." This stage is where the individual starts shaping or adjusting the role to fit her individual perspectives and desired outcomes versus her conforming to the role in the formal stage.

In engineering education, these are the accidental competencies and incompetencies identified by Walther et al. (2011).

4. Personal Stage

As individuals encounter the different role expectations of the earlier stages, they eventually reach a point in their development where "personal role expectations develop." Individuals begin the internalizing of the professional role and attempt to align it with their values and goals. This is the point that their identity as an engineer forms and continues to develop with repeated experiences of the cycle. Thornton and Nardi (1975) state that this final stage, in role acquisition, cannot occur until the individuals experience the various expectations of the earlier stages.

At the heart of this experience is a sense-making process that the engineering students must undergo as they grow from the highly idealized model they have for an engineer at the beginning to internalizing the role as part of who they are.

Ibarra's (2004) three basic processes for the development of professional identity add to these four stages:

- *Engagement with professional activities*: professional competencies are an important aspect of professional identity. Individuals build their professional identity through activities associated with the use of the professional competencies.

- *Developing social networks*: identity development is a social process. Steps 3 and 4, from the Role Acquisition model, are about the formal and informal interactions in the student social networks as they acquire the ability to perform competencies. The interactions are reinforced as they are practiced.

- *Sense-Making*: as with the Personal Stage of the Role Acquisition model, students must go through the sense-making process of coming to terms with professional competency expectations of the profession as it compares to their own personal beliefs and goals.

An engineering curriculum focused on developing professional competencies should offer multiple opportunities for students to engage in these processes. PBL and reflection activities, as part of the curriculum, provide students with these opportunities as they engage in the process of developing their professional identities.

5.4.3. PROFESSIONAL PRACTICE AND PROJECT-BASED LEARNING (PBL)

The potential and ability of PBL to develop the professional competencies were discussed earlier in Section 2.4. Highlighted was the identification by industry and employers as to their preference for PBL graduates. Part of this is the students' awareness and visible performance of professional competencies. In the calls for action from Chapter 1, the 2013 UNESCO Report on "Engineering Education: Transformation and Innovation" (Beanland & Hadgraft, 2013), the fourth step towards the transformation of engineering education is the utilization of Project-Based Learning in each year of the students' engineering education. The approach of PBL is best suited to the development of professional competencies and the growth of the student's professional identity.

In the use of the role acquisition as a model for developing the professional identity, the Walther et al. (2011) accidental competencies and incompetencies must be explicitly addressed at the informal stage. The results of their study "indicate that engineering students' overall competence is formed in a complex, socially situated learning environment through intricate learning processes with a wide range of varied influences at play." The importance of addressing this complexity is significant given that traditional teaching has shown to have limited impact on learning outcomes situated on the deep attitudinal level of the informal stage (ASCE, 2008). There is a clear need for an engineering educational method beyond the traditional lecture. Professional development occurs through experience and is influenced by the context in which it takes place (Eraut, 1994).

In Passow's (2012) study of ABET competencies, he identifies the need for utilizing the "context of professional practice." Professional practice creates a natural environment for the accidental competency learning and for avoiding or minimizing the in-competency learning. Sheppard's Educating Engineers (2009) identifies the need for professional practice or "spine" where students experience "practice-like" experiences as a central component of the educational process, thus students are enabled to "move from being passive *viewers* of engineering action to taking their places as active participants or *creators* within the field of engineering." Through this professional practice, students will develop the professional identity of an engineer.

As we seek to connect role acquisition and professional practice in developing the professional identity of engineering students, it is necessary to develop a curricular model that supports this. Felder and Brent (2003) identify PBL as an instructional model that can be readily adapted to achieve the professional competency development desired in engineering students. Du (2006) identifies that studying in a PBL curriculum goes far beyond just an instructional methodology; it develops an environment, which facilitates the professional identity development.

Several other prevalent publications identify the use of PBL as a critical component of transforming engineering education: Beanland and Hadgraft, in their 2013 UNESCO Report: Engineering Education; Sheppard et al. (2009) in Educating Engineering: Designing for the Future of the Field; Felder and Brent (2003) in Designing and Teaching Courses to Satisfy the ABET Engineering Criteria; and Litzinger et al. (2011) in Engineering Education and the Development of Expertise. These publications identify the potential of a PBL curriculum in developing the necessary professional competencies and identities of engineering students.

PBL can provide the opportunities for Ibarra's (2004) *Engagement with professional activities* and *Developing social networks* processes in the student development of their professional identity. Ibarra's *Sense-Making* process and Thornton and Nardi's (1975) *Personal Stage* of developing professional identity are predicated on the student taking what can be learned in the opportunities that a PBL program can provide and making it a real part of her personal being. Achieving this requires a reflection process on the part of the student.

5.4.4. REFLECTION

Schön (1987) identifies the importance of reflection in professional practice. It is also an important part of the professional identity development process in the education setting (Eliot & Turns, 2011). Elliot and Turns acknowledge that one could expect that reflection would naturally be a part of the student learning process. However, their study found students do not regularly participate in reflection activities unless it is made to be an explicit part of the curriculum. The method they found effective for making the reflective process explicit in developing the student professional identity is the use of portfolios, especially when approached in a "scaffolded manner." Work by Turns, Cuddihy, and Guan (2010) specifically explored the potential for portfolio construction as an activity to enhance learning in PBL experiences. Of greatest value in the portfolio construction, in terms of professional identity development was the reflection process.

Moon's work (2004) on reflection provides two definitions:

> "Reflection is a form of mental processing – a form of thinking – that may be used deliberately to fulfill a purpose or to achieve some anticipated outcome, or that may be an unexpected outcome from a state of 'being reflective'. It is applied to relatively complicated or unconstructed ideas for which there is not an obvious solution and is based on the further processing of knowledge and understanding and emotions that we already possess."

> "In an academic context, there is likely to be a conscious and stated purpose for the reflection, with an outcome stated in terms of learning or clarification – or, in particular, action. In this context, it is likely to be preceded by a description of the purpose and/or the subject matter of the reflection. The process and outcome of reflective work are most likely to be written and to be seen by others and both of these factors may influence its nature and the quality of the reflective process itself."

A critical part of the IRE PBL curriculum is making the reflection process explicit and frequent for students. The student ability to reflect in the complicated, unstructured ideas of the projects is an essential process for her to achieve the intended learning outcomes of the experiences, specifically the professional competency development. Moon suggestions for integrating reflection into higher education include the use of Professional Development Planning (PDP), reflective activities within the curricula, learning journals, and work-related learning with the purposeful inclusion of reflection. All four of these are incorporated into the IRE PBL curriculum.

Returning to Cowan's (2006) three-part model for reflection, from Section 2.2 of Volume 1, in which a learner reflects before learning, during learning, and after learning. Before learning is termed "reflection-for-action" where the learner connects prior learning to what is about to be learned. The learner then plans for the learning to come by setting goals, organizing resources, and purposefully determining the rate and effort to be expended on the learning. During the learning, the second reflection, "reflection-in-action," takes place, where the learner recaps what is being learned and how it is being learned. The learner takes this time to ensure alignment between the goals and the learning activity as well as predicting the likelihood of success of the learning. The final part of the model is the "reflection-on-action" where the learner identifies the value of the learning, evaluates the quality of the learning, and then describes how the learning will be carried forward.

Reflection is evident in Sheppard's spiral model; in Rompleman and de Graaff's model for aligning learning outcomes with instruction; and in Kolmos and de Graaff's model of PBL for both individual and team reflection. Reflection is a purposeful part of the IRE PBL model and is an important aspect of developing the students' professional identities and making explicit the development of their professional competencies.

5.4.5. CONCLUSION

This section focused on potential curricular elements for developing the student professional identity and visible professional competencies. The new PBL curriculum utilizes the curricular elements of competency outcome-based, role acquisition, PBL, and reflection to develop the content, incentive, and interaction dimensions of Illeris's model for the dimensions of learning. The professional competencies are explicit outcomes of the PBL program as students develop their identities as engineers through an adaptation of the four-stage role acquisition process. This process is anchored in the professional practice experience for students as they complete industry project as the core experience of the PBL program. Reflection is explicitly utilized to develop the professional identity and competencies of the students.

5.5. IRE CURRICULAR DESIGN FOR PROFESSIONAL COMPETENCIES

Chapters three and four described in greater detail the overall development of the IRE curriculum. This section looks specifically at the professional competency development aspect of the curriculum and its focus on identity development through role acquisition, professional practice, project-based learning, and reflection.

The proposed learning process for professional development in the new PBL curriculum was specifically developed to address the alignment gap between the desired outcomes for engineering graduates and those attained by graduates of traditional engineering programs (Ulseth, Froyd, Litzinger, Ewert, & Johnson, 2011). Built into the design is the Bransford et al. (2000) concepts for developing the foundation of learning systems: development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity, which were identified in Chapter 2.

5.5.1. PROFESSIONAL COMPETENCY AND IDENTITY DEVELOPMENT PROCESS

The process is best described as a development cycle. Specific to professional identity, the proposed professional competency development cycle incorporates the four stages of the Thornton and Nardi (1975) role acquisition model and embeds them in a professional practice spine of a four-semester design sequence. Each semester students build upon the professional competency knowledge of the previous semester. This is purposefully combined with a focus on the students experiencing this as a discovery-learning mode that is challenging and meaningful to them in support of their project work.

The professional competency development cycle starts directly with the anticipatory stage for each student at the beginning of every semester. Students create a professional development plan in which they reflect upon and identify where they are in their understanding of and abilities to perform the professional role of an engineer. Through a faculty-guided professional development self-assessment process, students identify:

- their current professional performance and abilities,
- what their professional growth goals are for the semester, and
- what planned activities they will participate in for the coming semester to achieve their professional development goals.

Throughout the semester, in the context of the professional practice projects, students experience the formal and informal stages of their role acquisition. The formal stage is centered on the PBL program's weekly professional development seminars. The first day of the week starts with a session called "seminar" where all students and staff participate in a formally structured seminar on a relevant professional development topic. On Wednesday, this topic is a structured part of the team's two-hour meeting with their project facilitator. In this meeting, a discussion is conducted on the development of the project; but just as importantly, the discussion also focuses on the professional development of the individuals on the team as it relates to that week's professional development topic. The week ends with each student reflecting in a journal on her development for the week, including her professional development. The entire week's professional development activities are about formalizing the expectations around a specific professional engineering competency and for the students to practice it in the PBL program.

The formal seminar, the weekly reflection structure, and the team structure are all designed to set up the informal stage and guide students towards the intentional professional learning outcomes and avoid the accidental incompetencies. As students look to adapt the expectations of that week's professional development seminar to fit their own individual perspectives, their peers have all heard the same message around the professional competency. This is intended to provide guidance and common language for their informal conversations among themselves as peers.

The mid-week meeting with their project facilitator aids the students in making this adaptation within a professionally supportive atmosphere. The difficulty of the adaptation is recognized, and they are coached through the adaptation process. The end of the week reflection activity, the reflection journal, provides the opportunity and expectation for students to identify how they will accept that week's professional topic within their own professional identities. An example of a reflection journal is found in Appendix F.

Cajander, Daniels, and von Kosky (2011) in their study of professional competency attainment at a Swedish university found the act of student reflection, in conjunction with formal assessment, advanced student development of professional competencies. They also found that students were not likely to practice reflection unless it was required for them to do it, reinforcing the value of the required weekly reflections in this new PBL model.

The vertically integrated teams provide for a professionally supportive, collegial atmosphere. Students who are at the beginning semesters of the program can benefit from constructive feedback (Trevelyan, 2014) from peers on their teams who are further along in their professional development. Thorton and Nardi identify these types of interactions as ones on which the students place the most value.

Also, the students who are further along in the curriculum benefit from having to guide the younger students. To do this, they must first reflect on their own understanding and experiences with a particular professional competency before they can guide the younger students in their development of the competency. The student interactions with their clients and faculty leaders also give them many venues to practice the use of their professional competencies and get formative, non-graded feedback on how to improve.

At the end of the semester, the personal stage is an integrated part of the assessments and grades for each student. Their facilitator evaluates her or his performance in all of the professionalism areas through a performance evaluation. It is meant to be similar to that which practicing engineers periodically undergo in the professional setting. The results of all of these experiences culminate in a chapter of the student's individualized personal development plan (PDP) for the semester.

The PDP chapter starts with a summary of the learning activities during the semester, the level of attainment of the goals from the previous semester, and is followed by a summary of the feedback the student has gotten during the performance evaluation. These inputs lead to the development of new goals for the next semester. Finally, the students create specific action plans detailing specific steps that can be taken to achieve the new goals. An example PDP is found in Appendix G.

Students complete this four-stage cycle, which is repeated in each of the four semesters of the upper-division program, with substantial progress toward the desired graduation-level professional outcomes being the requirement. At the heart of this process is Cowan's reflection model of "before – in – on reflection." The revisiting of the professional development topics with increasing level of sophistication each semester reflects the intent of the spiral configuration of the Networked Components Model proposed by Sheppard (2009). Ibarra (1999) and Marcia (1966) identified that professional identity development is, by its nature, a cyclical process of exploration and reflection. The cyclical model better reflects what is understood about learning and role acquisition than the more traditional, linear "one-time" through from the theory to the application model. Professional competencies account for three credits of student work each semester. A student's grade is solely dependent on the growth in these competency areas. The model is illustrated in Figure 5.1.

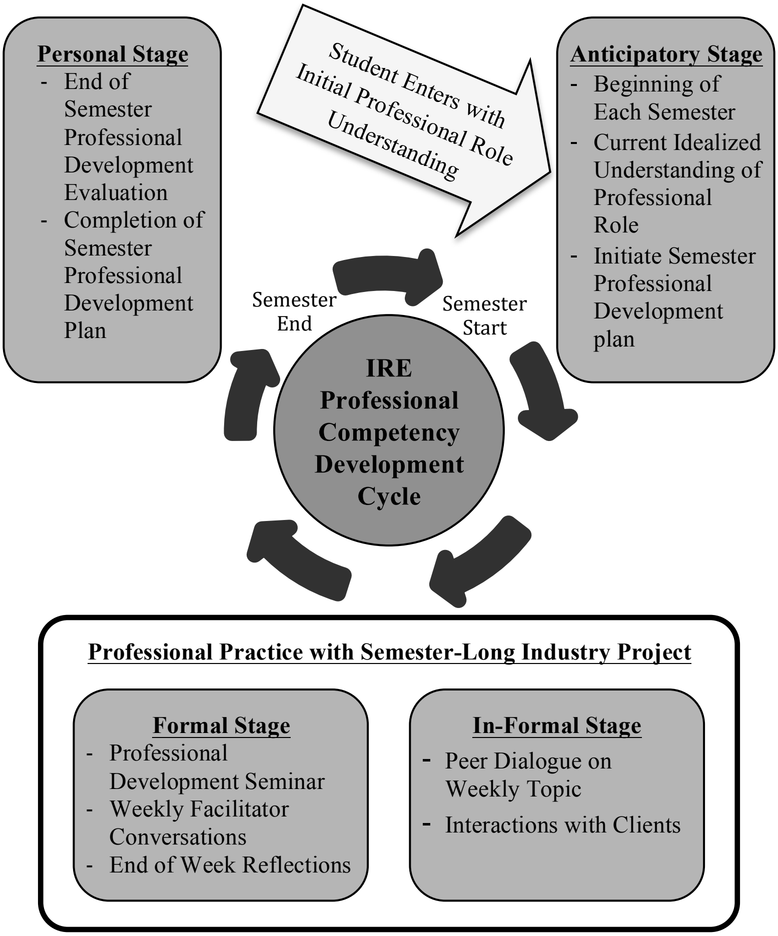

Figure 5.1. IRE PBL professional competency development semester cycle

5.5.2. CONNECT TO AALBORG MODEL

Positioning the new curriculum and the professional competency process in the context of PBL begins with relating it to the Aalborg PBL model. The Aalborg Model served as the inspiration for the teaching and learning approach of the Iron Range Engineering program (Kreck, 2013). Central to the Aalborg model are the project teams being facilitated by faculty project supervisors (Kofoed, Hansen, & Kolmos, 2004) in a dedicated group project space. The IRE developers adopted this model for the initial curriculum implementations in 2010. The project team, group room, project facilitator model remains unchanged and unmodified six years later, at the time of the publication of this thesis.

Another adoption from the Aalborg model is the concept of process analysis. "The objective of process analysis is for the students to develop awareness of the work and learning processes in order to become better project workers. Completion of the process analysis, which involves the student in documenting his/her reflections of the project process, has been a requirement in the (Aalborg) Basic Study Program since 1982" (Kofoed et al., 2004). The adaptation of process analysis at Iron Range Engineering extended beyond the project to the processes of personal, professional development through the PDP (professional development plan), and technical competence learning through the metacognitive memos. An example PDP is included in Appendix G.

Departure from the Aalborg model came as developers looked to conceive a new model for technical competency teaching and learning. The original faculty members and students created the concept of the "Learning Conversation" during the implementation phase during the pilot year. The philosophy behind learning conversations (see Section 4.4) was to have students access information between conversations and then bring questions to the discussion with their peers and teachers. Focus was placed on the conceptual understanding of fundamental concepts, in contrast to a focus on solving closed-ended problems using the fundamental concepts, as is prevalent in traditional engineering programs. The deliverable components of the technical competency were documentation of learning from personal learning and learning conversations, a deep-learning activity in which students used process learning to perform a "hands-on" activity, a metacognitive memo reflecting on the learning processes used and evaluating the effectiveness of the learning processes, and an oral examination focused on explaining the fundamental concepts and their application to the project.

5.5.3. CONNECT TO LITERATURE

We look at this model through the lens of Bransford's et al. (2000) foundations for learning of *development of expertise, reflection, metacognition, scaffolding, motivation, situativity, learning community, and identity*. The professional development plans are specifically focused on the *development of student expertise* by organizing their knowledge around the fundamental principles of engineering professionalism. This approach contrasts with the more prevalent novice approach in engineering education to focus primarily on memorization.

The PDP plan for the semester and the weekly professional development activities are specifically focused on structuring *reflection* in the student's experience. Webster-Wright (2009), in her education research study of professional learning across several professions, highlights critical reflection as a best practice. It is only through "challenging implicit assumptions and questioning taken-for-granted practices" that professional learning can change an individual's practice of professional competencies.

The aspect of assessing professional competencies at the beginning of the semester; developing a plan for improving them; and the end of the semester evaluation is intended to operationalize *metacognition* for the students. The PDP is individually focused to allow students to identify the professional competency progression they need to make towards graduation and the learning activities they need to take part in to meet graduation requirements. This focus on making *metacognition* very explicit to the students increases the degree to which students can transfer previous professional learning to new situations (Bransford et al., 2000).

Scaffolding is designed into the four-semester sequence cycle of the four stages of the professional competency development model. The scaffolding for students comes in the forms of mentoring by more experienced students on the project teams, semester and weekly conversations with the faculty facilitators, and faculty guidance in the formation of the semester Professional Development Plan (PDP). Students start in an "apprentice" mode in the first semester and then experience a progressive removal of the scaffolding as the professional development topics are revisited with an increasing level of sophistication each semester. Eventually, students begin mentoring younger students on their vertically integrated project teams.

Motivation and situativity have a clear connection as the learning environment incorporates the professional practice through the project work. The culture of real projects with real clients fosters an environment where the professional competencies provide genuine and immediate value to their work. Their grades and success as a student are a direct result of their professional competencies, thus creating genuine student motivation to learn them. In addition to the *motivation* from the profession practice, the *situativity* of the PBL learning community creates a social/cultural construct where professional competency is utilized and valued by the members as a necessary and integrated part of "their" *learning community*. The student engagement with the *learning community* further creates *motivation* for the student to develop professionally. Webster-Wright (2009) also identifies that empirical research supports the importance of a community that supports professional learning.

Identity comes throughout an engineer's education and career as she builds a concept of herself as related to the activities and values of the profession. The four-stage IRE PBL professional competency development cycle is intentional to develop a realistic perception of students' level of professional competency and provide continuous feedback from the environment around them as they develop.

Connecting the IRE PBL professional competency development cycle back to Illeris's model of learning, the PDP, weekly seminars, and weekly reflection form the content dimensions of the internal interaction process as illustrated in Figure 5.2.

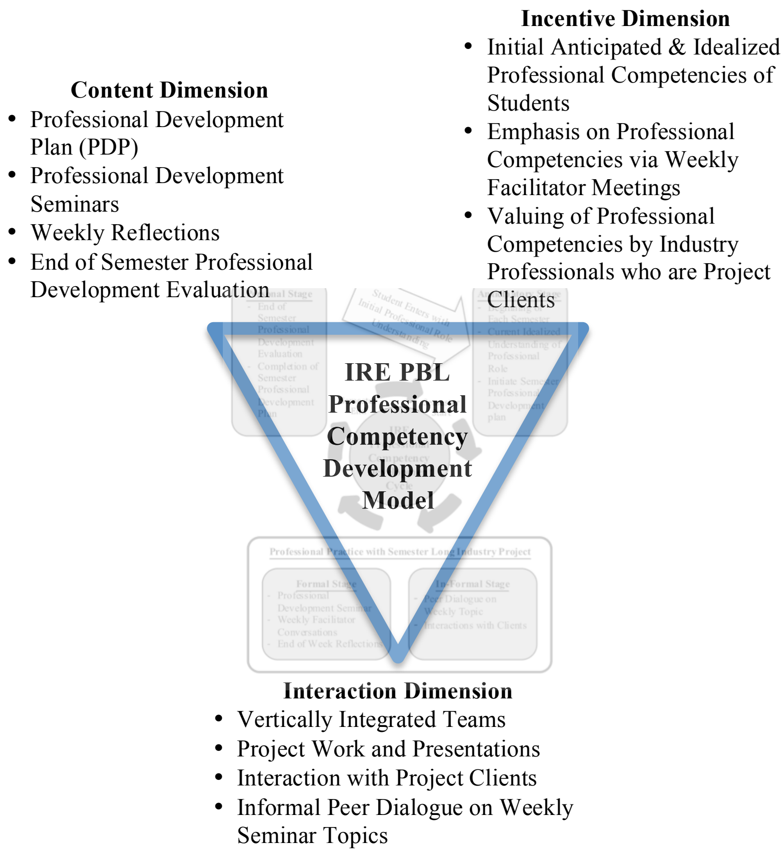

Figure 5.2. Placement of IRE PBL professional competency development cycle on Illeris model

The explicitness and celebration of student professional development in the program forms the incentive/emotion dimension of the internal iteration process for the student learning. The celebration and embracement of the professional competency development by the students and faculty of the learning community creates an environment that supports the interaction dimension identified as the external interactions dimension of Illeris's model. The IRE PBL professional competency development semester cycle placement is at the intersection of the three dimensions of the Illeris model as illustrated in Figure 5.2.

5.6. IMPACT OF THE IRE PBL PROFESSIONAL COMPETENCY DEVELOPMENT CYCLE

This chapter has described a curriculum developed from what is best understood regarding the development of professional competencies through the formation of the student professional identity. It is positioned within the Illeris (2007) framework for learning and with the Bransford (2000) foundational concepts for learning. PBL is identified as an approach of promise for the student development of professional competencies. The research question for the new PBL curriculum described is:

> "In what ways does the Project-Based Learning (PBL) curriculum influence the development of professional competencies?"

Answering this question will take place through bringing together the answers for three sub-questions:

1. What do students define as professional competencies?

2. What is the growth of the student professional competencies in a PBL curriculum?

3. What are the development experiences for professional competencies in the PBL curriculum?

The research will not only focus on how they experience the development of professional competencies but which curricular elements they identify in developing the professional competencies; specifically, the curriculum elements of identity development through role acquisition, professional practice, project-based learning, and reflection.

Chapter 6 will develop a research approach for evaluating the curriculum's influence on the student development of student professional competencies. The evaluation will include looking both at the visible professional competencies that are developed through the formation of the student professional identity.

Chapter 7 will look at the development of the professional competencies as evaluated through a quantitative analysis. It will compare the development growth of students in the IRE PBL model to the growth of the students in a traditional upper-division engineering program. It will include looking at both the internal (individual) interactions and external (team) interactions from Illeris's model for evaluating the development.

How students experienced the development of the professional competencies through the formation of their professional identity will be the focus of Chapter 8 through a qualitative analysis of the PBL student experience. It will determine whether students identify the elements of the IRE PBL Professional Competency Development Cycle as part of developing their professional identities and how they experienced them.

CHAPTER 6. RESEARCH METHODOLOGY

The framework put forth by Borrego and Bernhard (2011) for "quality scholarship in engineering education" will be used in the development of this study:

- "Inspired by real educational problems.
- Informed by theory and other literature describing prior work within and beyond the field/home country.
- Systematic and intentional, with documented decisions ideally based on well-planned collection and analysis of empirical data.
- Consistent with the perspectives and methodologies chosen (quantitative, qualitative, or mixed).
- Presented (at least in part) in a form that engineering academic staff can understand and use, including by discussing implications of the research.
- Situated in international and interdisciplinary contexts, by demonstrating awareness of how common the problem is, what is being pursued elsewhere, and the likelihood that results are or are not generalizable/transferable to other contexts (disciplines and/or countries). We note that in order for an EER topic to be worthy of inquiry, it need not be broadly generalizable" (Borrego & Bernhard, 2011).

First, this research project is inspired by the need for engineering education to change and the real regional educational needs described in the previous chapters, informed by theory and literature. Chapter 5 presented the theoretical basis for the project-based learning approach that was presented to meet the needed improvement in the student development of professional competencies. This theoretical basis provides both an approach to developing students' professional competencies and also a lens through which to evaluate the student development of professional competencies (Bernhard & Baillie, 2013). It also situates this work in the context of the international need for change in engineering education. The remaining quality criteria are addressed as they are developed in later sections.

This study of the IRE curriculum will look at both the professional competencies that are developed through the formation of the student professional identity. It will seek to answer what ways the PBL curriculum influences the student development of professional competencies. This study was designed as an explanatory sequential mixed method. First, the way the PBL curriculum influences their student development will be evaluated through a quantitative study to identify student development of professional competencies. Based on the results of the quantitative study, the qualitative study will be developed to explain the results through an understanding of the ways in which students experienced their development of professional competencies.

This chapter sets up the research methodology for the study following Creswell's (2014) three components for planning a research approach: 1) the philosophical worldview (epistemology) assumptions for the study, 2) a research design (methodology) based upon the philosophical worldview, and 3) the research methods that translate the study into practice. The methodology development will continue in Chapters 7 and 8 along with the methods used for the quantitative and qualitative studies. The decisions regarding the methodology will be "systematic and intentional" to best answer the research questions.

6.1. EPISTEMOLOGY

A review of the literature of epistemological perspectives groups them into four main perspectives (Case & Light, 2011; Creswell, 2014; Koro‐Ljungberg & Douglas, 2008; Merriam, 2009):

1. Positivist/Post-positivist
2. Interpretive/Constructivist
3. Critical Theory/Transformative
4. Postmodern/Post-structural.

Creswell proposes an alternate group, *Pragmatism.*

The positivist/post-positivist perspectives are "hypothesis-driven and center on establishing cause and effect relationships" (Case & Light, 2011). The other three perspectives, the "situational perspectives" group, are each different from the other but collectively different from the positivist/post-positivist perspective in that "they are focused on delivering understandings of particular situations and experiences. They are generally inductive in approach and allow for insights and findings to emerge throughout the data collection and analysis process" (Case & Light, 2011). The pragmatism perspective is not committed to any specific philosophical viewpoint, but instead takes the position that a worldview or "truth" is what works at the time to understand the consequences of real-world actions and situations being observed. Creswell (2014) identifies that the pragmatism often takes a postmodern turn.

The Interpretive/Constructivist perspective has applicability in this study. This perspective assumes that the reality is socially constructed (Merriam, 2009). It is about individuals developing meaning in their experiences as they seek understanding of the world around them (Creswell, 2014). In this study, the world is the educational and social setting of the PBL curriculum. The process of building identity, described in Chapter 5, is a transformative process taking students from their initial attributes as they start the program to graduate attributes as they complete the education process. The learning process is one in which the learner "constructs knowledge on the basis of prior knowledge and additionally acquired information" (Rompelman & de Graaff, 2006). This process is based on a constructivism perspective (Jonassen et al., 1999).

Critical to understanding this process are the experiences of students as they develop their professional identity. A constructivism perspective focuses on the student experience and inductively develops both meaning and understanding of the students' experiences as the data is analyzed. This research study will utilize a constructivist epistemology perspective to develop the methodology for this study.

The post-positivist perspective is also an integral part of the study. One of the original motivations for this study was to determine whether the PBL curriculum has an effect on the student development of professional competencies. Asking "how" they develop this means not only understanding the student perspective of the experience, but also the effect of these experiences on their potential to utilize professional knowledge and skills in the complexity of real-life engineering situations. This is the definition of professional competencies from Chapter 5. This study will use both constructivist and post-positivist epistemology perspectives combined with a pragmatic research approach to develop a mixed-methods approach that uses both a qualitative and quantitative perspective, respectfully associated with of these epistemology perspectives.

The need for both quantitative and qualitative results in the Post-Positivist and Interpretive/Constructivist perspectives, respectfully, leads to a pragmatic perspective for the overall methodology of the research. In addition to answering the research questions, this type of approach increases the potential for the study to interest and inform engineering educators. Borrego, Douglas, and Amelink (2009), in their observation of an international engineering education conference, identified engineering educators as having "a strong preference for quantitative methods and their associated evaluation criteria, likely due to most participants' technical training." Although the participants valued and expected qualitative work, they "enacted a quantitative classroom-experimental model in critiquing each others' work."

It is this researcher's position that there is a clear need to establish a quantitative understanding of ways in which the project-based learning (PBL) curriculum influences the student development of professional competencies. Then, if there is an established quantitative difference identified with the PBL curriculum in the student development of professional competencies, it creates a natural need for the study and engineering education audience to have the development explained through a qualitative study. This mixed-methods approach will present the research in a "form that engineering academic staff can understand and use" (Borrego & Bernhard, 2011).

Other epistemological perspectives considered for this study were Critical Theory/Transformative and Postmodern/Post-structural. They were determined not to fit the scope of the study, and therefore were not utilized. The Critical Theory/Transformative is focused more on the political power for the purpose of transformation. Postpositivist assumptions are felt to impose "structural laws and theories that do not fit marginalized individuals in our society" or properly address the "issues of power and social justice, discrimination, and oppression" (Creswell, 2014). Constructivist viewpoints are thought not to go far enough to advocate for these issues. The development of professional competencies is held to be important by the researcher and is already an adequate focus for both the national and international engineering education communities; therefore, a Critical Theory/Transformative perspective does not fit the purpose of this study.

The Postmodern/Post-structural perspective is quite different from the post-positivist, constructivist, and critical perspectives (Merriam, 2009). There is no one truth to describe something; there are multiple truths. Merriam recognizes the systemic influence this perspective is having on qualitative studies. In regards to this study, it is combined, in the next section, with self-determination theory to recognize that each student has a unique way that he experiences the development of his professional competencies. The study will first develop an understanding of the extent this specific PBL experience influences the student development of professional competencies, and then it will create a collective student experience to describe this development; a pure Postmodern/Post-structural perspective would run counter to this focus.

6.2. MIXED-METHODS DESIGN

The selection of the pragmatic mixed-methods approach to the research methodology is made on the premise that it better answers the research question than either a quantitative or qualitative study can. Creswell (2014) identifies this advantage in his definition for mixed methods:

> "*Mixed-methods research* is an approach to inquiry involving collecting both quantitative and qualitative data, integrating the two forms of data, and using distinct designs that may involve philosophical assumptions and theoretical frameworks. The core assumption of this form of inquiry

> is that the combination of qualitative and quantitative approaches provides a more complete understanding of the research problem than either approach alone" (Creswell, 2014).

The use of a mixed-method approach provides a more complete understanding of the ways the PBL curriculum influences the student development of professional competencies. The mixed methods will provide an explanation for the quantitative study on the effect of the curriculum on professional competency development through the development of a composite structure of the students' experiences in developing their professional identities from the qualitative study.

Of the different types of mixed-methods designs, the explanatory sequential mixed-methods design is best for meeting the above justification of using a mixed-methods approach. The emphasis in this approach is to first understand the effect through a quantitative approach and then explain or develop understanding through a qualitative approach. Creswell (2014) describes this design as a distinct two-phase project where the quantitative study is completed as the first phase. The results of this study are interpreted and then used to develop the second phase qualitative study (Borrego et al., 2009). The results from each phase are analyzed and interpreted separately. A third interpretation is then conducted to determine how the qualitative findings can help explain the results of the quantitative study (Trochim, 2005).

Creswell and Clark (2011) identify that the explanatory design has several strengths that apply to this study. First, it appeals to the initial quantitative focus, which, as mentioned earlier, is common in engineering education. Its two-phase structure also makes it easier for a single researcher to implement. The quantitative and qualitative results can be analyzed and discussed separately to create a clear delineation for the reader. It also allows the qualitative phase to be more emergent and further develop an understanding of what is found in the quantitative study.

This study began with this traditional explanatory sequential design with the intent to focus on the results of the quantitative data and then understand them better through the qualitative study. Cresswell and Clark's (2007) notation refers to this as a QUAN → qual mixed-methods approach. Upper case refers to the major focus, and lower case refers to a minor focus.

However, as the study progressed, elements of a convergent design emerged. Specifically emerging was the recognition that the qualitative results had equal or greater value than the quantitative results. The study became QUAN → QUAL in the notation of Cresswell and Clark. This further reinforced the use of "pragmatism to provide an 'umbrella' paradigm to the research study" (Creswell & Clark, 2011) and not focus on a single epistemological perspective for the research approach.

The choice to not focus on a single epistemological perspective was confirmed while conducting the study.

Thus, a mixed-method approach was developed for this study. The quantitative was developed and conducted first. The conclusions from the quantitative study were used to develop the qualitative study that followed. The results of the quantitative study where then used to explain the quantitative study. The results from both studies were interpreted and used equally to answer the research question. The next two sections will develop the methodology for the quantitative and qualitative parts of the mixed-methods study.

6.3. QUANTITATIVE METHODOLOGY

Understanding the ways in which the Project-Based Learning (PBL) curriculum influences the development of professional competencies starts with answering the second sub-research question, "What is the growth of the student professional competencies in a PBL curriculum?" Growth is defined as the difference between the students' professional competencies before the PBL experience as compared to after the PBL experience. For this pre- to post- comparison, a post-positivist perspective quantitative comparison study will be used.

The post-positivist perspective, adopted for the quantitative phase, has a hypothesis focus, and the topics studied through this perspective have a cause-and-effect focus (Case & Light, 2011). The hypothesis(es) being tested and the research question(s) determined the methods for data collection and analysis (Borrego et al., 2009).

The post-positive perspective is one in which cause and effect (outcome) relationships do exist. It is not a position in which the cause absolutely determines the effect or outcome, but one in which a "probable" causation exists (Borrego et al., 2009). For this study, the cause is the student experience of the PBL curriculum. The effect is the growth in the student professional competencies.

The methodology begins with the development of the theory and hypothesis(es), followed by, in Chapter 7, the approach to collecting data, analysis of the data, and then the interpretation of the results to evaluate the theory (Borrego et al., 2009). The theory for this study was developed in Chapter 5 and will continue specific to the quantitative study. It would be anticipated that a student experiencing the PBL model described in Chapter 3 and the professional competency development cycle from Chapter 5 would see a probable increase in the student professional competencies. How to measure this effect is a critical step in answering the research question.

First, it is important to return to the definition established in Chapter 5 for professional competencies, "the potential that students have to use professional knowledge and skills to perform in the complexity of a real-life engineering situation." Central to this definition is the ability that students have to perform the professional competencies.

There is also the base of the iceberg, the student's traits, self-conception, and motives, which are considered an important foundation for these competencies (Spencer & Spencer, 1993). This is the professional identity part of the professional competency development cycle identified in Chapter 5. The student identity is continually informed, formed, and reformed over time through a self-evaluation process as each student interacts with others (Cooper & Olson, 1996) and reflects on those experiences. The self-evaluation process is not only critical to the professional identity development of the student, but it also provides an insight into each student's current achievement level in developing the professional competencies. The students' insight into her own abilities can be greater than what an external evaluator or instructor can identify (Boud & Falchikov, 1989). In this study, the level of achievement will be determined through a student self-evaluation process. Thus, an emphasis is placed on the students' self-reporting in her level of professional competency development.

If we look at self-conception, it is the mental image of one's self, "the perception or image of our abilities and our uniqueness. At first, one's self-concept is very general and changeable… As we grow older, these self-perceptions become much more organized, detailed, and specific" (Pastorino & Doyle-Portillo, 2013). An individual's self-concept is fluid and ever-changing as the perceptions of one's ability are compared to the ideal self, which the individual would like to possess. The ideal self is the idealized self-concept that the individual would most like to possess and upon which high importance is placed (Rogers, 1958). Rogers identifies that how well an individual's self-concept actually matches to reality is the congruence between the self and the actual experience. It is an ongoing process of self-evaluation that involves interpretation and reinterpretation of the experiences one lives through (Kerby, 1991) in comparison to the degree of congruence between one's self-concept and the actual experience of their performance of the professional competencies. The identification of incongruence as individuals negotiate within social roles or situations (Wah Tan, 1997) creates the personal identification of the need for reforming the individual's self-identity (Cooper & Olson, 1996), thus creating personal growth. Critical to this process is the individual's self-evaluated performance. **The performance of professional competencies will be the focus of this research study.**

Nias, Southworth, and Yeomans (1989) identified that people are often threatened when they face changes to their identities. They often develop coping strategies to "protect themselves" instead of being forced to perceive themselves in a way that is not congruent with their idealized self-concept. Yet, people are able to change, adjust, or grow in their identities. Essential to the willingness to change and move past being threatened is the motivation they develop to accomplish this.

Looking to self-determination theory, motivation creates the desire to act, to grow in one's identity. Ryan and Deci (2000) state that "Human beings can be proactive and engaged or, alternatively, passive and alienated, largely as a function of the social conditions in which they develop and function." On a continuum from non-self-determined to fully self-determined, the more autonomous the motivation an individual has, the more internalized the motivation is, which is associated with "more engagement (Connell & Wellborn, 1991), better performance (Miserandino, 1996) …. higher quality learning (Grolnick & Ryan, 1989)." The regulatory process associated with the more internalized motivation is associated with the individuals who are identifying with or finding importance in the learning process. Therefore, this **study also includes an evaluation of the importance the students have for these professional competencies.**

Returning to this study's anticipation that students experiencing the new PBL curriculum would see a probable increase in their professional competencies, we will incorporate the emphasis on students' self-reporting their level of professional competency in both **importance** and **performance**. The quantitative portion of this research study will focus on the following directional hypotheses:

- *Hypothesis one*: PBL students will have an increase in their self-reported importance for professional competencies.
- *Hypothesis two*: This self-reported importance increase will be greater for PBL students than the increase for non-PBL students.
- *Hypothesis three*: PBL students will have an increase in their self-reported performance for professional competencies.
- *Hypothesis four*: This self-reported performance increase will be greater for PBL students than the increase for non-PBL students.

For a quantitative, post-positivist study design, the two main relevant methodology options are descriptive statistics or experimental research (Borrego et al., 2009; Creswell, 2014). The descriptive statistics utilize a survey approach to provide a quantitative description of attitudes, trends, or opinions in the sample group from the population being studied. It is a descriptive study that describes the characteristics of the sample population, which can be applied to the entire population, but do not identify cause-and-effect relationships. This approach will not work well for this study as the evaluation for the potential cause and effect between the PBL curriculum experience and the professional outcome is a desired result of the research work.

The experimental research methodology is a better fit for this research work. It seeks to identify if the treatment has a probable causal effect on the variables of interest in the study.

Chapter 7 will continue the development of the methodology and methods for the quantitative phase. The development of professional competencies will be described. The methods for collecting data, analyzing the data, and discussion of the results will focus on answering the second sub research question, "What is the growth of the student professional competencies in a PBL curriculum?" As part of this phase, two instruments for measuring the development of professional competencies will be developed in Chapter 7. The instruments will be used both pre- and post- with students experiencing the PBL curriculum and also pre- and post- with students experiencing a non-PBL upper-division program at regional universities. Results pre- to post- for both groups and comparatively between groups will be analyzed to develop an understanding of the growth in students' professional competencies. The results from the quantitative study will be used to inform the development of the qualitative study.

6.4. QUALITATIVE METHODOLOGY

The qualitative study follows and is informed by the quantitative study. For the qualitative phase, a constructivist epistemology perspective will be adopted. It has many more options for methodologies than the post-positivist perspective. This section will review and select the methodology for the qualitative portion of the research study. Chapter 8 will continue the description of the methodology and methods as they emerged from the findings of the quantitative study.

In qualitative studies, the primary interest is in "understanding the meaning people have constructed, that is, how people make sense of their world and the experiences they have in the world" (Merriam, 2009). In the qualitative portion of this research study, the primary interests are to understand the meaning students have constructed for their professional identity, how they make sense of the PBL curriculum, and the experiences they had in the PBL curriculum, specifically as it relates to the development of professional competencies.

The methodological approach that is the best fit for the quantitative study is phenomenology.

> "Phenomenological research is a design of inquiry coming from philosophy and psychology in which the researcher describes the lived experiences of individuals about a phenomenon as described by the participants. This description culminates in the essence of the experiences for several individuals who have all experienced the phenomenon" (Creswell, 2014).

Phenomenology is not focused on reducing the phenomena experience to an abstract understanding; rather it is focused on studying the participants' experiences and interpretations to "depict the essence or basic structure of (the) experience" (Merriam, 2009). Merriam describes the use of an interview as the primary approach to data collection for getting at the experience's underlying structure or essence. The phenomenological process begins with the researcher exploring experiences that influence his own understanding of the experience being studied. The transcripts from the interviews are systemically reduced to develop individual and composite structural descriptions of the experience. They, in turn, are integrated to "develop a synthesis of the meaning and essences of the phenomenon or experiences" (Moustakas, 1994). The synthesis of the meaning and essences of the PBL curriculum experience for the student development of professional competencies is sought as the outcome or results leave the quantitative portion of this research study.

The following methodologies were also considered for use as the methodology for conducting the qualitative portion of this study (Borrego et al., 2009; Case & Light, 2011; Creswell, 2014; Merriam, 2009):

- Ethnography – cultural description of an experience from observation of participants in an experience to identify the critical dimensions of the experience
- Discourse Analysis – focus on the language used in discourse (classroom discussion transcripts, written text, and use of mathematical equations, graphs, figures, etc.) by the participants to gain understanding of their beliefs and values
- Narrative Analysis – formation of a collaborative narrative from collecting and analyzing stories from participants to understand the experience of interest
- Phenomenography – develops a collection of the different ways particpants describe their experience. The focus is on the difference in description of the experiences
- Grounded Theory – theory is generated from the data at hand through multiple, iterative stages of data collection and theory refinement
- Case Study – in-depth analysis of a bounded system or case to discover "findings" that emerge and can be applied to other cases

For this study, *discourse analysis* and *grounded theory* were eliminated from being used as a methodology because they do not directly focus on developing an understanding of the students' experience in development of their professional identity. *Ethnography* and *case study* were eliminated because it was not possible to fully observe or analyze the entire system due to the experience of the professional identity development took place over the entire two-year period of their PBL curricular experience. The *narrative analysis* is eliminated as a methodology, not for its intended outcome, but because the collection of stories will not provide the degree of focus desired on the professional identity development experience. The student stories may focus on several other aspects of the PBL curriculum without specific guidance for participants to focus on the professional competency development experiences. *Phenomenography*, which focuses on identifying the different ways that participants experience a phenomenon (Case & Light, 2011), was considered but was not selected as it focuses more on the different ways a phenomenon is experienced versus developing a composite understanding of the experience as phenomenology does.

The synthesis of the meaning and essences from how students experienced the PBL curriculum in developing their professional competencies as identified through the quantitative portion of this research study are intended to explain the results of the quantitative study. They will also be used, in conjunction with the quantitative results, to provide an interpretation of the ways the PBL curriculum influences student development of professional competencies.

The phenomenology methodology will be further developed in Chapter 8 as it emerges relative to the specific findings of the quantitative study. In addition, the methods for the qualitative study will be developed, along with a description of the study, analysis of the data, and a summary of the results.

6.5. RESEARCH METHODOLOGY SUMMARY

Creswell (2014) adds three factors for determining a research approach in addition to 1) the philosophical worldview (epistemology and ontology) assumptions for the study, 2) a research design (methodology) based upon the philosophical worldview, and 3) the research methods that translate the study into practice mentioned at the beginning of Chapter 6. They are "the research problem, the personal experiences of the researcher, and the audience(s) for whom the report will be written." These three factors will be used in this chapter summary as a lens to review the research approach developed.

The Research Problem

The research question lends itself well to a mixed-methods research approach:

> "In what ways does the project-based learning (PBL) curriculum influence the development of professional competencies?"

The question first implies the need to understand if there is any probable effect of the PBL curriculum on the student development of professional competencies. This post-positivist perspective (Phillips & Burbules, 2000) would lead to a quantitative study as the logical approach as part of answering the research question.

Given the social constructivism nature of a PBL model of engineering education, using a quantitative model exclusively provides only a partial description of the student professional competency development experience. Fully answering this research question requires attention to understanding which elements of the curriculum influenced the student experience and what are the essences of the collective student experience. Such a focus on increasing the understanding of the students' experience supports an interpretivism/constructivist approach to the research question (Case & Light, 2011) and would suggest a qualitative approach to answering the research question such that a phenomenological approach can provide.

Thus, answering the research question leads to a pragmatic epistemology perspective that has both post-positive and the interpretive/constructivist elements. Following a statement from Johnson and Onwuegbuzie (2004), "[w]hat is most fundamental are the research questions – research methods should follow research questions in a way that offers the best chance to obtain useful answers," the research will utilize a mixed-methods approach that combines both the post-positivist and the constructivist approaches with the third additional analysis to answer better the research question than the sum of the two separate research approaches.

Researcher Personal Experiences

This PhD student and the PBL program developers all come from engineering backgrounds. Thus, their personal experiences naturally create an interest in knowing "how well" something meets a design goal. In the instance of creating this new PBL program, there is the interest to identify if there is any probable effect from the PBL curriculum on the student development of professional competencies. The professional competency development was one of the drivers for the implementation of the new PBL curriculum. This interest creates a natural inclination for a quantitative research approach (Borrego et al., 2009).

As professional educators, there is also desire to understand more than just if there is any effect from the treatment. It is equally important, if not more so, to understand how the students experienced the curriculum in the development of professional competencies. A qualitative research approach would focus on increasing the understanding of this experience, thus creating a research inclination towards a qualitative study. These dual interests of the researcher and the program developers also support both the quantitative and qualitative approaches through a mixed-methods approach.

Audience for this Research

Although project-based learning is not new in the world, its usage in the U.S. engineering educational context provides an opportunity for a new audience to understand its potential in transforming the U.S. engineering educational system. Although a single study would not, by itself, establish the ability of PBL to provide the needed transformation, the data from this study can provide some initial indications of its potential. The importance of quantitative data in accomplishing this is identified by Borrego et al. (2009) in their study of an international engineering education conference, which identified engineering educators as having "a strong preference for quantitative methods and their associated evaluation criteria, likely due to most participants' technical training." This creates a natural need for the U.S. engineering education audience to first understand the research question through a quantitative study.

This same study identified that once an understanding of quantitative results is established, the discussion naturally shifts to seeking an understanding of why the results occurred. Similar to this study, once the probable effect of this new PBL curriculum on the student professional competency development trajectory is analyzed, it is important to develop an understanding of how the students experienced the development process and what curricular elements they identified through a qualitative study. Again a mixed-method approach best meets both of these needs. Given the U.S. engineering education community's preference for empirical evidence and the PBL curriculum's reflection of the northern and central European preference for authentic, complex problems, the mixed-methods represents the quality criteria of presenting the results in a form that can be understood and used by engineering academic staff from international communities (Borrego & Bernhard, 2011).

In summary, this mixed-methods study will address the research question, "In what ways does the Project-Based Learning (PBL) curriculum influence the development of professional competencies?" An explanatory mixed-methods design will be used with equal emphasis on quantitative and qualitative data.

Chapter 7 will focus on the quantitative analysis and will compare the development of students in the IRE PBL model to the development of students in a traditional upper-division engineering program. It will include looking at both the internal (individual) interactions and external (team) interactions from Illeris's model for evaluating the development. Two professional competency instruments will be developed to test the hypothesis that students who experience the PBL curriculum will have an increase in their importance for and performance of professional competencies and that this increase will be greater for PBL students than for non-PBL students. The PBL students will be students in the Iron Range Engineering (IRE) PBL program. The non-PBL students will be students at a "traditional" upper-division engineering program from the same geographical region in the U.S.A.

The qualitative phase will be conducted, as a follow-up to the quantitative results, to identify how students in the PBL curriculum experienced the development of professional competencies. Developing a collective composite student experience for the development of these professional competencies, as seen through the lens of professional identity formation, will be the focus of Chapter 8. It will be conducted with a group of recent graduates from the IRE PBL curriculum.

Chapter 9 will pull together the results of the quantitative and qualitative studies and provide a third interpretation of the results to complete the mixed-method study. It will provide a more compete explanation of how students develop professional competencies in the PBL curriculum. Figure 6.1 provides a graphical layout of the research chronology for the mixed-methods approach developed for this study.

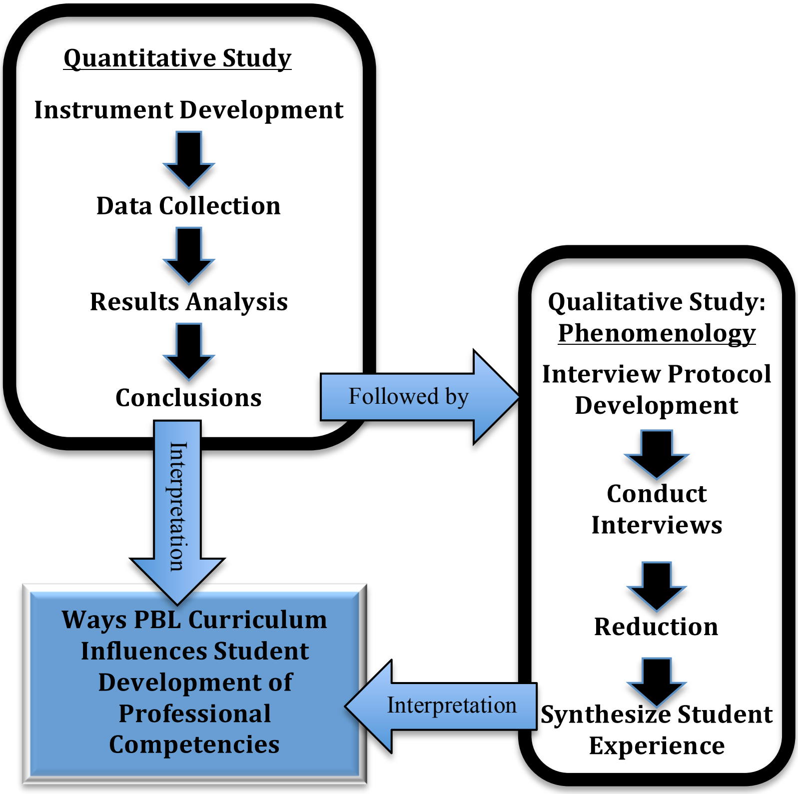

Figure 6.1. Research methodology – mixed methods

Chapter 6 has developed the research approach for evaluating the curriculum's influence on the student development of student professional competencies. The evaluation begins in Chapter 7 with the comparison of the development of students in the IRE PBL model to the development of students in a traditional upper-division engineering program. The evaluation will include both the internal (individual) interactions and external (team) interactions from Illeris's model.

CHAPTER 7. QUANTITATIVE STUDY OF PROFESSIONAL COMPETENCY DEVELOPMENT

The quantitative portion of this study, which focuses on understanding the ways the Project-Based Learning (PBL) curriculum influences the development of professional competencies, through answering the second sub-research question, "What is the growth of the student professional competencies in a PBL curriculum?" The study will look at the student development for both the internal (individual) interactions and external (team) interactions from Illeris's model for evaluating the development.

The development of the students in the PBL curriculum will be compared to the development of students in a more traditional upper-division engineering program. Based on the theoretical perspective and the professional competency development cycle described in Chapter 5, the PBL curriculum is expected to have a probable effect of growth in student professional competencies. This growth for the students experiencing the PBL curriculum is expected to be greater than the growth for students experiencing the traditional upper-division engineering program.

This chapter will describe 1) the quantitative methods, 2) the professional competency instrument development, 3) the methods and procedures, 4) analyze the results, and developing a 5) summary of the quantitative study.

7.1. QUANTITATIVE METHODS

The quantitative study participants come from two groups. The first group is the PBL group who experienced the two years of PBL curriculum for their upper-division engineering education. The second group is the non-PBL group who experienced a traditional curriculum for the two years of their upper-division engineering experiences.

Since the students have already pre-selected themselves into these naturally formed groups, based upon which type of curricular experience they preferred prior to the study, a fully randomized design cannot be implemented, as is more often preferred in educational research (Olds, Moskal, & Miller, 2005). Instead, the quasi-experiment method of matching (Creswell, 2014) will be used where the students will be grouped into the two groups based upon their pre-selected preferences. The initial starting points of both groups will be analyzed and compared to see if this method introduces any bias in the starting point of the two groups. Since students for both groups will come from traditional lower-division programs, it is anticipated that there should be little difference seen between the two starting points.

The independent variable in this study is the PBL curriculum experienced by the PBL group but not the comparative non-PBL group. The dependent variables being evaluated are the students' self-reported growth in their 1) importance for and 2) performance of their professional competencies. Growth will be measured through a pre- and post- comparison. The growth of each group will be evaluated through a pre-assessment at the beginning of the their upper-division program and then a post-assessment upon completion of their respective programs. The difference between the pre- and post-assessments will indicative as each group's respective growth in their professional competencies.

7.2. PROFESSIONAL COMPETENCY INSTRUMENT DEVELOPMENT

Shuman et al. (2005) identified that there is a lack of clearly recognized and well-established means for assessment of student professional competencies. This necessitates the creation of an instrument for this study, which can be used, for the experimental assessment of the student self-reported importance for and performance of professional competencies in the context of the U.S. engineering education system.

Two instruments were developed to evaluate the professional competency growth of students in the PBL model as compared to students studying in a more traditional model. They were based on the internal (individual) interactions and external (team) interactions from Illeris's model from Chapter 5. The first instrument, the *Individual Professional Competency Instrument*, focuses on the individual professional competencies emphasizing the internal or individual interactions. The second instrument, the *Team Professional Competency Instrument*, focuses on the student professional competencies for external interactions, specifically in the team context.

Individual Professional Competency Instrument

The Dehing et al. (2013) study on professional competency and identity identified the individual dimension of the student development. As the engineering students both position themselves and allow others to position them relative to normative standards (Stevens et al., 2008), it is important for students to frame the normative standards in a context and in a way that is identifiable by them at this point in their professional careers.

The individual professional competency instrument was developed, as part of this study, with this in mind. Its normative standards are based on the ABET student outcomes found in Criteria 3 (ABET, 2015). They are the focus of this study:

- an ability to function on multi-disciplinary teams (3.d);
- an understanding of professional and ethical responsibility (3.f); and
- an ability to communicate effectively (3.g).

In the fall of 2012, a group of the PBL students participated in a workshop where they were first trained on the ABET student outcomes. They then developed a list of 19 individual professional behavioral expectations that reflected these outcomes in their own language and context as students. The list was used to develop the items in Table 7.1. These were the behaviors, constructs, that the students identified as the visible actions for the normative standards from the ABET criteria.

Table 7.1. Individual professional development instrument items

Function on Multi-Disciplinary Team (3.d)	**Understanding of Professional and Ethical Responsibility (3.f)**	**Ability to Communicate Effectively (3.g)**
• Arrive at all meetings on time • Treat all others with respect • Meet the needs of your team by completing work on time and of high-quality • Give proactive feedback to others • Do not take frustrations out on those around you	• When told something, record and act upon it • Dress and groom appropriately • Work hard to create an environment free of harassment and conducive to learning • Willingly help others inside and outside of University • Meet all deadlines • Schedule time to better yourself through reading current events • Act ethically in all respects • Continually seek to improve yourself • Maintain a positive attitude • Act safely while completing all tasks	• Read memos and respond appropriately • Speak professionally, free of vulgarities and with appropriate grammar • Pay close attention to your emails and respond to requests in a timely manner

Each of these behavioral expectations is presented to participants taking the instrument with the following statement:

> "Engineering students are expected to act professionally with one another, with facilitators, and with external people. Below is a list of important professional behavior expectations that engineering students and graduates should follow."

Students are then asked to rate (1 = Low, 5 = High) each expectation item on both:

a) its importance to your personal success and

b) your current level of performance.

Rate as:

- Low (1) if not relevant to the project or to my personal/professional life
- Medium (3) if moderately important to the project and/or my personal/professional life
- High (5) if important or very important to the project and my personal/professional life

A scale with a mid-point was used to avoid pushing respondents towards the positive end of the scale, which can occur with a scale that has no mid-point (Worcester & Burns, 1975).

Team Professional Competency Instrument

The second instrument, the *Team Professional Development Instrument*, identifies students' beliefs about the importance of professional competencies and their current performance level within the context of functioning as a member of a team. It is focused on the social dimension from Illeris and Dehning. Unlike the development of the individual professional competency instrument, the literature review identified the TIDEE professional development work of Davis et al. (2011) in a team context. It was used, with permission, as a framework to guide the development of this instrument.

<u>The TIDEE Professional Ability Expectations In a Team Setting, with Descriptions</u>

- **<u>Analyzing information</u>** Applying analysis methods/tools to understand & explain conditions
- **<u>Solving problems</u>** Formulating, selecting, and implementing actions for optimal outcomes
- **<u>Designing solutions</u>** Producing creative, practical products that bring value to varied stakeholders

- **Researching questions** Investigating, processing, interpreting information to answer important questions
- **Communicating** Receiving, processing, sharing information to achieve the desired impact
- **Collaborating** Working with a team to achieve collective & individual goals
- **Relating inclusively** Valuing and sustaining a supportive environment for all knowledge & perspectives
- **Leading others** Developing shared vision & plans; empowering to achieve individual & mutual goals
- **Practicing self-growth** Planning, self-assessing, & achieving goals for personal development
- **Being a high achiever** Delivering consistently high-quality work & results on time
- **Adapting to change** Being aware, responding proactively to social, global, & technological change
- **Serving professionally** Serving with integrity, responsibility & sensitivity to individual & societal norms

All twelve behavioral expectations are used verbatim from the TIDEE Professional Development Model (Beyerlein, Davis, & Trevisan, 2012). The adaptation is the addition of the 1-5 Likert-scale to place their ability on a continuum for each of these constructs.

Each of the expectations is presented in the instrument to participants with the following statement:

> "Many engineering projects challenge and stretch the abilities of people involved. This exercise guides you through steps to identify knowledge or skill deficits in your project team and to create a plan for growing your abilities to meet these needs. With instructor feedback and focused effort on your part, you will increase your ability to perform as a professional and become a better independent learner. The first step in planning professional development is to identify abilities needed to be successful. The twelve abilities listed throughout the survey are a good place to begin" (Beyerlein, Davis, & Trevisan, 2012).

Students are asked to rate each ability (and associated behaviors listed) (1 = Low, 5 = High), in the social context of preforming on a team, for:

a) its importance to your personal and project success, and

b) your current level of performance.

Rate as:

- Low (1) if not relevant to the project or to my personal/professional life
- Medium (3) if moderately important to the project and/or my personal/professional life
- High (5) if important or very important to the project and my personal/professional life

Team Professional Competency Instrument

Both of these instruments are adapted to a web format utilizing Survey Monkey (Sue & Ritter, 2012). Since both parts of this instrument are developed and/or adapted specifically for this study, its validity and reliability must be established to a reasonable level as part of the research.

Content validity (Moskal, Reed, & Strong, 2014) is the main basis for the validity of the instruments. The content of the first individual performance instrument is based directly on the ABET Criteria 3 (2003) itself. The criteria represent the core characteristics identified by engineering education, industry, and practicing professionals as the attributes that education curriculum should focus on for engineering student professional development. The validity of the second team performance instrument is based on the TIDEE work of Davis et al. (2011). The items represent the professional expectations identified in this work for providing guidance in the development of student professional abilities in a team context. The instrument developed is a direct adaptation of each item for this research. Therefore, the content of this part of the tool is directly aligned with TIDEE, and its content validity is based on the validity of the TIDEE content itself.

The test reliability will be established though a statistical analysis of the data. Cronbach's Alpha will be used a method to determine the reliability of both parts of the instrument (Moskal et al., 2014). Since the instruments were administered separately, each part's reliability will be evaluated separately. If each part has a large coefficient, it can be concluded that the there is little specific item variance and any observed variance can be attributed to the group factors (Cortina, 1993) of the PBL curriculum and the non-PBL curriculum educational experiences.

7.3. DATA COLLECTION PROCESS

In the data collection process for both instruments, participants in both the PBL experiment group and the non-PBL control group will complete the instruments at the beginning of their junior year and then again near the completion of their senior year. The data collection process specific to the PBL experiment group consists of the following steps:

1. The PBL program director acts as a evaluation administrator and requests PBL students to complete both professional competency instruments as part of their orientation to the PBL program. This was done for the five cohorts who started the PBL program in Fall 2012, Fall 2013, Spring 2014, Fall 2014, and Spring 2014 respectively.
2. The students are exposed to and complete the upper-division PBL program.
3. The PBL program director requests PBL students to complete the professional competency instruments a second time as part of their end of the program activities. This was done for four of the above cohorts who finished the PBL program in the Spring 2013, Spring 2014, Fall 2014, and Spring 2015 respectively.
4. A comparison of pre- and post- results for the PBL treatment students is conducted.

The PBL experiment group had a pre- sample size of 56 students and a post- sample size of 30 students.

The data collection process specific to the non-PBL control group consists of a similar set of steps:

1. A faculty member at the traditional institution acts as an evaluation administrator and a representative group of students to complete the professional development instrument at the beginning of their upper-division course work. This was done for three cohorts who started at regional traditional engineering programs in Fall 2013, Fall 2014, and Fall 2014.
2. The students are exposed to and complete the “traditional” non-PBL upper-division program.
3. The evaluation administrator the representative group of students to complete the professional development instrument a second time as part of their end of program activities. This was done for three cohorts who completed regional traditional engineering programs in Spring 2013, Spring 2014, and Spring 2015.
4. A comparison of pre- and post-control group treatment results for the non-PBL treatment students is conducted.

The non-PBL control group has a pre- sample size of 108 students and a post-sample size of 101 students. Table 7.2 details the number of students completing the instrument.

Table 7.2. Number of students completing both instruments

	Comparison Group		**PBL Group**	
	pre-nonPBL	post-nonPBL	pre-PBL	post-PBL
Number of students (n)	108	101	56	30

7.4. RESULTS

The results for each instrument allow for multiple comparisons to see if there are differences between the groups:

- ***PBL/Non-PBL Pre:*** PBL students who took instrument prior to (pre-) PBL upper-division compared to Non-PBL who took the instrument prior to (pre-) traditional upper-division program.

- ***PBL Student Pre-Post***: PBL students taking instrument prior to (pre-) PBL upper-division compared to PBL students taking instrument after (post-) PBL upper-division program.

- ***Non-PBL Student Pre-Post***: non-PBL students taking instrument prior to (pre-) traditional upper-division compared to non-PBL students taking instrument after (post-) traditional upper-division program.

- ***PBL/Non-PBL Post:*** PBL students who took instrument after (post-) PBL upper-division compared to Non-PBL who took the instrument after (post-) traditional upper-division program.

The results for each instrument item and the overall composite instrument score for each data set were initially analyzed for means and standard deviations. An Independent-means *t*-test was then conducted, using the SPSS software package version 22, to test whether differences exist between the groups' means in the above comparisons (Field, 2009). A Levene's test was completed regarding the assumption of homogeneity of variances and used to determine which SPSS test statistic output to use from the *t*-test. An independent *t*-test was used because the scores are from different people in each group and, therefore, independent. Results are displayed in Table 7.3 and Figure 7.2, 7.3, and 7.4.

*Table 7.3. Composite pre-post professional competency differences with standard deviations (SD) – **bold italics if significant difference***

		PBL Group Composite Scores			Non-PBL Group Composite Scores		
		Pre	Post	Difference	Pre	Post	Difference
Individual Professional Competency Instrument (All 19 Item Composite)	*Performance*	***4.03*** SD= .48	***4.28*** SD= .33	***0.25*** *t = 2.48* *sig. = .015*	4.06 SD= .58	4.15 SD= .51	0.09 *t = 1.13* *sig. = .257*
	Importance	4.70 SD= .35	4.69 SD= .28	-0.01 *t = -.084* *sig. = .933*	**4.56** SD= .54	**4.42** SD= .52	**-0.14** *t = -1.97* *sig. = .050*
Team Professional Competency Instrument (All 12 Item Composite)	*Performance*	***3.59*** SD= .52	***3.98*** SD= .47	***0.39*** *t = 3.48* *sig. = .001*	3.88 SD= .58	3.93 SD= .54	0.05 *t = .514* *sig. = .609*
	Importance	4.56 SD= .44	4.64 SD= .30	0.08 *t = .926* *sig. = .357*	4.54 SD= .48	4.47 SD= .58	-0.07 *t = -.914* *sig. = .362*

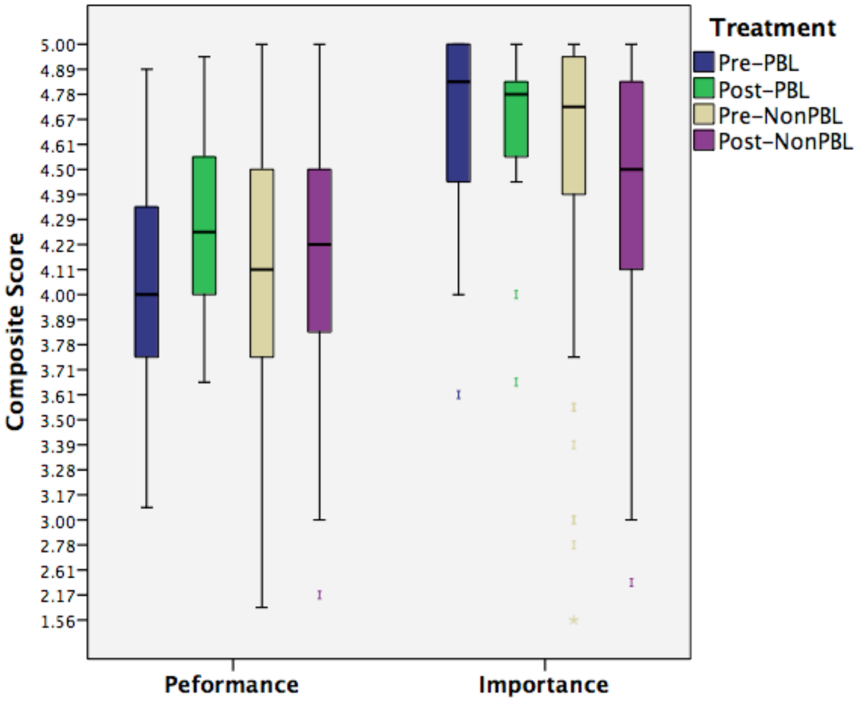

Figure 7.2. Boxplot of composite scores for individual professional competency instrument for both performance and importance

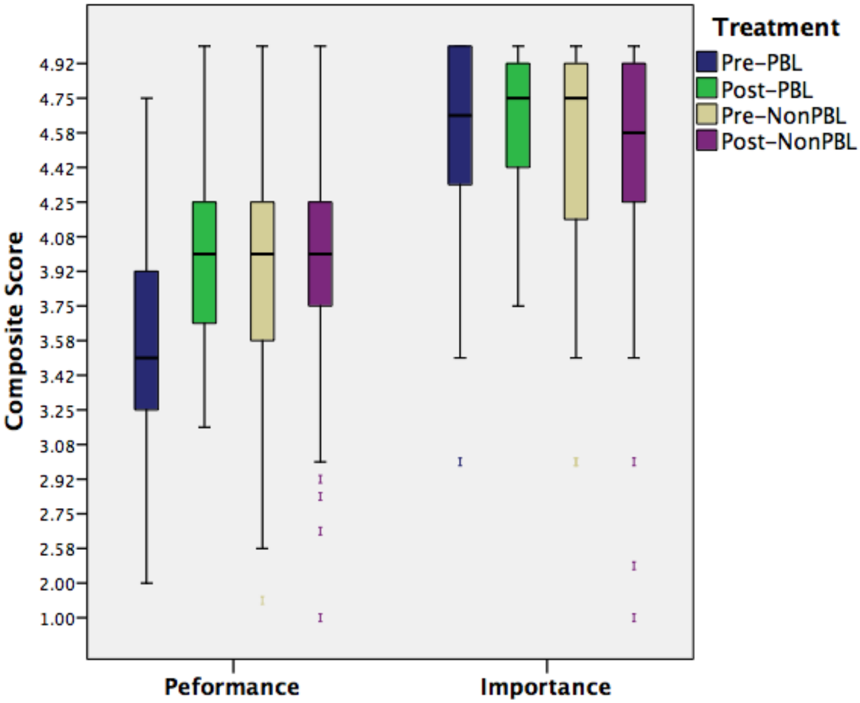

Figure 7.3. Boxplot of composite scores for team professional competency instrument for both performance and importance

Figure 7.4 shows sixteen overall comparisons. A comparison of both instruments for both importance and performance is shown 1) pre-PBL to pre-non-PBL, 2) pre-PBL to post-PBL, 3) pre-non-PBL to post-non-PBL, and 4) post-PBL to post-non-PBL. Triple lines and gray boxes indicate comparisons of significance.

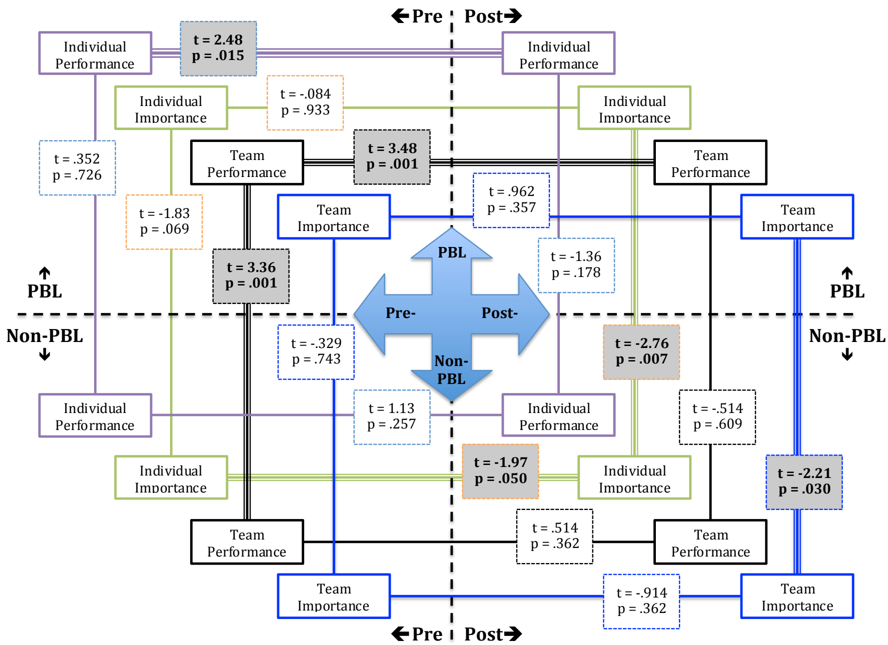

Figure 7.4. t and significance scores for a comparison of composite means

PBL to non-PBL Pre- Composite Score Comparison - The Pre- scores for each group indicate no pre-treatment differences between PBL and non-PBL groups in Performance for the *Individual Instrument* t = .352, p > .05; Importance for the *Individual Instrument* t = 1.83 , p > .05; and Importance for the *Team Instrument* t = .329, p > .05. There is a difference between the groups for the self-reported performance for the *Team Instrument* t = -3.36, p < .05. The Pre- non-PBL (M = 3.89, SD = .58) mean composite score was 0.30 higher than the Pre- PBL cohort (M = 3.59, SD = .52).

PBL Student Pre-Post - Results indicate that students who experienced the PBL curriculum self-reported a Pre-Post difference in performance for *Team Instrument t* = 2.48, p < .05. The Post- composite score (M = 4.0, SD = .47) was 0.39 higher than the Pre- composite score (M = 3.6, SD = .52). There was an increase of 0.25 in the Pre-Post difference Performance for the *Individual Instrument* t = 3.48, p < .05. The results indicate no difference in the Pre-Post composite scores for the PBL students in Importance for the *Individual Instrument,* t = .084, p > .05, or for the *Team Instrument,* t = .926, p > .05.

Non-PBL Student Pre-Post - The results for the non-PBL students indicate no change in the composite score for Performance in either instrument or Importance for the *Team Instrument.* There was a statistically significant composite score decrease of -0.14 for Importance Pre- (M = 4.56, SD = .54) to Post- (M = 4.42, SD = .52) in the *Individual Instrument.*

PBL to non-PBL Post- Composite Score Comparison - The Post- scores for each group indicate that there are no probable differences between the Post- scores for Performance in the *Individual Instrument* $t = 1.356$, $p > .05$ or the *Team Instrument* $t = .514$, $p > .05$.

The Importance for both instruments does show a difference in composite Post-scores. The Importance score for *Individual Instrument* Post- score $t = 2.76$, $p < .05$ is 0.27 higher for the PBL group (M= 4.69) is 0.27 higher than the non-PBL group (M = 4.42). There is a 0.17 difference in the composite Importance score for *Team Instrument* Post- scores $t = 2.21$, $p < .05$ between the PBL (M = 4.64) and the non-PBL (M = 4.47).

Difference in Individual Instrument Item Scores – a review of the scores at an individual item level identifies the PBL group showing a positive difference in 15 instrument items and the non-PBL group showing a positive difference in two instrument items, as shown in Table 7.2. The non-PBL group had four items of decrease.

Table 7.4. Individual instrument items of growth

(***I:*** - individual instrument, **T*:*** - team instrument)

PBL Group Growth Items	**Pre-Score Mean**	**Post-Score Mean**	**Diff-erence**	***t***	***Sig. (2-tailed)***
I: **Performance:** When told something act upon it	3.76	4.17	0.41	2.17	.033
I: **Performance:** Willing help others outside of engineering environment	4.22	4.70	0.48	3.06	.003
I: **Performance:** Meet team needs by getting work done on time & quality	4.04	4.37	0.33	2.04	.045
I: **Performance:** Act safely while completing tasks	4.11	4.40	0.29	2.32	.023
I: **Performance:** Pay close attention to email & timely responsible	3.96	4.47	0.51	2.90	.005
I: **Importance:** Act safely while completing tasks	4.67	4.90	0.23	2.02	.047
I: **Importance:** Pay close attention to email & timely response	4.70	4.93	0.23	2.36	.021
T: **Performance:** Analyzing information	3.38	3.97	0.61	3.88	.000
T: **Performance:** Solving problems	3.39	3.97	0.60	3.06	.003
T: **Performance:** Researching questions	3.45	4.00	0.55	2.65	.006
T: **Performance:** Communicating	3.59	4.23	0.64	3.65	.001
T: **Performance:** Relating inclusively	3.66	4.17	0.51	3.14	.001
T: **Performance:** Leading others	3.55	3.93	0.38	2.22	.030

T: **Performance:** Practicing self growth	3.41	3.90	0.49	2.85	.003
T: **Importance:** Researching questions	4.39	4.77	0.38	2.43	.017
Non – PBL Group Growth Items					
I: **Performance:** Read memos and respond appropriately	3.87	4.16	0.29	2.63	.009
I: **Performance:** Pay close attention to email & timely response	3.88	4.22	0.34	2.58	.010
I: **Importance:** Speak professionally	4.56	4.25	***-0.31***	-2.73	.007
I: **Importance:** Meet all deadlines	4.74	4.51	***-0.23***	-2.45	.015
I: **Importance:** Schedule time to better yourself	4.06	3.76	***-0.30***	-2.15	.032
T: **Importance:** Serving Professionally	4.63	4.41	***-0.22***	-2.15	.033

For all 30-test items, the individual item Post- scores for the PBL group were higher or equal to the individual item Post- scores for the non-PBL group. The non-PBL group was not higher on any test item.

Cronbach's Alpha, the most common measure of scale reliability (Field, 2009), was used to indicate the overall reliability of the instruments. A Cronbach Alpha analysis was completed for each instrument for both Performance and Importance; a total of four analyses. In each analysis, the overall Cronbach's Alpha, the *Correction Item-Total Correlation*, and the *Cronbach's Alpha if Item is Deleted* was reviewed as the output of the SPSS Cronbach scale analysis (Field, 2009). For all four analyses, the *Correction Item-Total Correlation* was above 0.3 for each instrument item and no items were identified for an increase in the "*Cronbach's Alpha if Item is Deleted.*" The Cronbach's Alpha for all four instruments was above 0.8 indicating that any score variance is more likely due to actual differences than specific item variability (Cortina, 1993; Kline, 2000). The Cronbach's Alphas are:

- Performance - *Individual Instrument*: 0.891
- Importance - *Individual Instrument*: 0.938
- Performance - *Team Instrument*: 0.880
- Importance - *Team Instrument*: 0.903

7.5. DISCUSSION OF QUANTITATIVE RESULTS

Looking at the means comparison for the Pre- treatment condition of each group, the two groups appear similar in their self-reporting for Importance as indicated by both instruments. Focusing on the Performance items for the professional competency instruments, there was no difference indicated between the Pre- scores for either group in the *Individual Instrument.* These results indicate that, as expected, the life experiences and lower-division curricular experiences of the students is similar for the development of the Importance for professional competencies and their self-reported ability for Performance of professional competencies as an individual.

However, the *Team Instrument* does indicate a probable difference between the two groups in their starting point for self-reported Performance in a team context. The non-PBL cohort self-reported a higher mean composite score of 3.9 for the Performance items in the *Team Instrument,* as compared to the composite 3.6 mean score for the PBL cohort. The Pre- difference between the two groups in the Performance items in the *Team Instrument* was not expected.

One plausible explanation is that the students who entered the PBL program primarily came from the same community college lower-division engineering program that is nationally recognized for its use of engineering projects in its lower-division curriculum (Johnson & Ulseth, 2011). This increased exposure to engineering team experience could have led to students having more context in the complexity of team work and therefore rated themselves lower in their performance ability. Although this differences in starting points is interesting, it is not the focus of this research work and therefore will be left for further investigation in a different research project. It will be revisited in the Post- score discussion.

The Pre- and Post- differences for each group are the main focus of this study to see if there is probable support for each of the four hypotheses. From the current quantitative analysis, there is evidence to indicate support for hypotheses three and four. The students who experienced the PBL curriculum do indicate a self-reported difference in the professional ability performance and this difference is greater in comparison to the difference shown by students in the non-PBL control group. The non-PBL group showed no statistically significant difference, Pre- to Post-, in their self-reported performance of the professional competencies.

The results do not, however, support hypotheses one and two. Students in the PBL curriculum group do not show statistically significant difference Pre- to Post- in the overall importance for professional abilities. The results were the same for the non-PBL group for Importance as indicated by the *Team Instrument*. The non-PBL group actually showed a decrease in Importance as measured by the *Individual Instrument.* This could be attributed to the result of Walther's "Accidental Incompetencies" discussed in Chapter 5. Further explanations and developing an understanding of this result through a follow-up qualitative study are beyond the scope of this research work, as representatives from this group were not interviewed.

The similarity of the scores in Importance at both the starting point, and to some extent the ending point for both groups, indicates that the importance these engineering students had for professional competencies was primarily established prior to beginning their upper-division programs. It also indicates that the upper-division experience has no significant impact on the importance students have for the professional competencies. Explaining these results will be explored further in the qualitative analysis.

Connecting this back to the self-determination theory discussion earlier in this volume, both groups appear to start with similar potential in their motivation and therefore similar potential in their identifying with or finding importance in the learning process of professional competencies. This, in turn, creates the same potential in students for having similar motivations associated with their level of engagement, performance, and quality of learning. Therefore, given the same potential starting point for importance, any differences in growth for performance between the two groups could be attributed to the learning process and curriculum they experience in the upper-division.

The Post- comparison of the two groups shows no difference in the self-reported Performance of professional competencies for both instruments. This is interesting given that the PBL group reported an increase in both instruments and the non-PBL group did not show a Pre- to Post- comparison increase in either instrument.

Did the PBL students just start lower and then rise up to the Non-PBL students after upper-division? Did the PBL students have a better understanding of their own Performance abilities of professional competencies to start with as compared to the Non-PBL students? Therefore, they then rated themselves more realistically in the beginning. The Non-PBL students either had no real growth or their understanding of the Performance of professional competencies increased over the two-year period and therefore resulted in a more realistic rating of themselves in the Post- state such that any growth Pre- to Post- indicated no difference.

Developing a better understanding of what happened with the Non-PBL students would require developing an understanding of how the two groups interpreted the scale at the Pre- and Post- conditions and comparing them. Such a study is beyond the scope of this research, as representatives of the Non-PBL group were not accessible for participation in the follow-up qualitative study.

Focusing on the individual *Importance* items, the PBL cohort did show growth in three individual items. In the *Individual Instrument,* the items of growth for importance are “Act Safely” and “Pay Close Attention to Email & Timely Response.” For the *Team Instrument,* the item of growth for importance was the “Researching Questions (Investigating, processing, interpreting information to answer important questions).” All three of these items were also items of self-reported growth in performance for their respective instruments.

The non-PBL group had a decrease in four items for Importance. Three items were from the *Individual Instrument:* “Speak professionally, free of vulgarities and with appropriate grammar,” “Meet all deadlines,” and “Schedule time to better yourself through reading current events.” The one item from the *Team Instrument* was “Serving Professionally - Serving with integrity, responsibility & sensitivity to individual & societal norms.” Having items decrease is not surprising given the *Individual Instrument* composite score decreased Pre- to Post- for the non-PBL group.

Focusing on the individual Performance items, the PBL group had an increase for 12 of the 30 items. The non-PBL group had only two items of increase. This provides additional support for hypotheses three and four.

As proposed in *hypothesis 3*, there is a growth or increase in the PBL group composite score for the Performance items with both instruments. Also, as proposed in *hypothesis 4,* the growth or increase in the PBL composite scores for the Performance items with both instruments is greater than that for the non-PBL group, which had no difference Pre- to Post-. Both of these hypotheses were supported by the literature in Chapter 5. Therefore, the growth for the PBL group is an expected outcome of the PBL treatment.

The support for hypotheses three and four is also found in a follow-up study of graduates from the PBL graduates and their employers (Ulseth and Johnson, 2015). This study found that the graduates and their employers were satisfied with the engineering preparation of the PBL model graduates as compared to the performance of non-PBL graduates.

7.6. QUANTITATIVE RESULTS SUMMARY

The key findings of the quantitative study are:

- Non-PBL group reports a higher pre- composite for *Team Performance* as compared to PBL group
- Non-PBL group has lower post- composite score in *Importance* for both instruments as compared to PBL Group
- Non-PBL group reduces in *Importance* (pre- to post-) for *Individual* instrument
- PBL increases in *Performance* (pre- to post-) for both instruments
- PBL has no change in *Importance* (pre- to post-) for both instruments. Scores start and stay at a high level.

The quantitative results indicate probable support of hypothesis 3 and hypothesis 4 but not for hypothesis 1 and hypothesis 2. The first aspect of the qualitative study is to gain an understanding of why the students in the PBL group do not show the expected increase in the importance of professional competencies that was proposed in hypotheses one and two.

Although the quantitative data shows promising results for the influence of the PBL curriculum on the student performance of professional competencies, it gives little insight as to how the students experience the curriculum and the development of the ability to perform. The focus of the qualitative study is to gain an understanding of the student experience and also identify which elements of the PBL curriculum affected the student professional competency development experience. This will provide further explanation of the promising quantitative study results.

CHAPTER 8. QUALITATIVE STUDY OF PROFESSIONAL COMPETENCY DEVELOPMENT

The focus for Chapter 8 is developing an understanding of how students experienced the development of the professional competencies. As the second phase of the explanatory sequential mixed-methods research approach, the qualitative study seeks to explain the results of the quantitative study (Creswell, 2014) from Chapter 7 in describing the development of the professional competencies by the students in the PBL curriculum. Of particular interest is the PBL group's increase in professional competency performance (pre- to post-) and the PBL group beginning with and maintaining a high level of importance for he professional competencies. This Chapter will describe the qualitative study 1) methodology, 2) instrument development, 3) methods, 4) results, and 5) summary.

8.1. QUALITATIVE METHODOLOGY

It was anticipated that a student experiencing the PBL model described in chapter 3 and the professional competency development cycle from Chapter 5 would see a probable effect on his professional competency development. The results from the quantitative study indicate that the students saw an increased development in their ability to perform the professional competencies. Explaining how the student experienced this growth or development is an important step in answering the research question of how students develop professional competencies in this new PBL curriculum.

Of equal interest is to gain an understanding of the students' experience in how they develop the importance for the professional competencies, as students did not indicate an increase in their importance for professional competencies pre- to post-PBL.

It is important to again return to the definition of professional competencies established in Chapter 5. It is "the potential that students have to use professional knowledge and skills to perform in the complexity of a real-life engineering situation." Central to this definition is the ability to perform the professional competencies. This is the visible ability that students have to perform the professional competencies and is the tip of the iceberg in the Spencer and Spencer (1993) analogy for professional competencies. While Chapter 7 looked at this visible tip, the qualitative study looks more at the base of the iceberg, the students' traits, self-conception and motives, which are the important foundation for these competencies. They make up the students' professional identity.

In Chapter 5, self-conception was developed as being a fluid and an ever-changing perception of one's abilities or competencies as they are compared to the ideal self. The ideal self is the idealized self-concept that the individual would most like to possess and upon which high importance is placed (Rogers, 1958). Rogers identified that self-concept is organized and formed through self-experiences. He defines self-experiences as "being any event or entity in the phenomenal field discriminated by the individual which is also discriminated as, 'self,' 'me,' 'I,' or related thereto."

The qualitative study develops the collective student self-experience of the PBL curriculum. The self-conception is ever changing for each individual and the student experience in the program itself changes, due to the social dimension of the learning. Consequently, it is important to note that the collective student self-experience developed in this study is for the moment and time the participants experienced the PBL program.

The first aspect of the qualitative study is developing an understanding of the students' self-experiences, as they relate to the self-conception of their importance for professional competencies. Of particular interest to the study is understanding when and where students experienced developing their importance. This will help explain why they did not identify an increase in the importance for professional competencies. An increase was expected as a probable outcome of the students in the PBL curriculum.

The second aspect of the qualitative study is to develop an understanding of the student experience to explain further the increase in the performance of professional competencies. It will focus on explaining in more depth:

- How did students experience the development of professional competencies?
- Which curricular elements of PBL do they identify as contributing to the probable growth in performance of professional abilities?

Since the intent of the qualitative study is to further explain the results of the quantitative study, the participants will be a subset of the original quantitative study participants (Creswell, 2014). The participants are PBL students who completed, or recently completed, the PBL curriculum in the Spring of 2015. They have the most recent immersion in the PBL curriculum as they have just completed the program at the time of the interviews.

Establishing the phenomenological methods for this study starts, first, with recognizing that phenomenology develops a deeper understanding of the participant experiences through a close examination of each experience to “produce rich thematic descriptions that provide insight into the meaning of the lived experience” (Starks & Trinidad, 2007). Its focuses on developing a culminating experience as described by participants to depict the basic structure of the professional identity development experience. The focus of the researcher in the phenomenology is describing the phenomenon as accurately as possible, without including any biases (Groenewald, 2004).

Phenomenology methods cannot be reduced to a specific set of repeatable steps or set of instructions (Keen, 1982). Instead of specific steps, Moustakas (1994) identifies the main processes to follow in a phenomenological research: 1) Epoche, 2) Phenomenological Reduction, 3) Imaginative Variations, and 4) Synthesis. Moustakas’s approach is identified for conducting a phenomenological research study by both Creswell (2014) and Merriam (2009).

In the *Epoche* process, Moustakas states the intention is to significantly reduce the preconceived viewpoints, biases, and judgments. It prepares the researcher to derive new knowledge and approach the interview and data analysis with an unbiased, receptive presence. The process is a meditative procedure where the researcher focuses on and thinks about his or her preconceptions and prejudgments of an experience and identifies them as a list, or “brackets” them (Groenewald, 2004). The list is reviewed and reflected upon to “bracket” them out to make the researcher more receptive and able to approach the study in a more pressuppositionless state (Moustakas, 1994).

For this study, my list of preconceptions and prejudgments, as the researcher, for the bracketing process is:

- Professional development is a cyclical experience, (Sheppard et al., 2009), and must take place over multiple experiences
- For the development process to be effective, it must be guided by the faculty
- Professional/project practice or experience is necessary for professional development
- Not all competencies (or habits) are desired or positive; desired competencies must be cultivated
- PBL is an effective way to develop professional competencies

These items are the result of my experience as a practicing engineer, my experiences as an engineering educator, my own personal engineering education experiences, and my academic pursuit to better understand and improve engineering education. As the qualitative study continues, as the researcher, I will be cognizant of this list and seek to "bracket" it out of how each interview is approached and experienced.

Phenomenological Reduction is the process of describing in textual language the collective experience of the phenomena. In this research, it is the student experience for the development of professional competencies in a PBL curriculum. The first aspect for the *Phenomenological Reduction* is bracketing the research question(s) and setting aside other aspects of the experience.

For this research project, the bracketing includes 1) understanding the student self-experience as it relates to the importance for professional competencies and 2) understanding the student self-experience related to developing the student performance of professional competencies through the students' experiences. It specifically focuses on:

- How did students experience the development of professional competencies?
- Which curricular elements of PBL do they identify as contributing to the probable growth in performance of professional abilities?

Other aspects of the student experience in the PBL curriculum may be self-identified by the students, but they will be bracketed out of the study.

The second aspect of the *Phenomenological Reduction* process is "horizontalization" (Moustakas, 1994) or "delineating units of meaning" (Groenewald, 2004). Each distinct statement made by the student, describing the experience or aspect of the experience as a horizon, and from horizontalized statements a "unit of meaning" is listed for the student. No value statement is placed upon them at this point, nor is there a limit to their number. Each horizon is the "grounding or condition of the phenomenon that gives it a distinctive character" (Moustakas, 1994). The listed units of meaning are extracted from each interview and then scrutinized for clear redundancy.

The third aspect of the *Phenomenological Reduction* process is the "clustering" of the units of meaning into common categories or themes. The clusters are formed through grouping together those with similar meaning (Creswell, 2014; Moustakas, 1994).

The final aspect of the *Phenomenological Reduction* is "organizing" the units of meaning and themes into a coherent, "composite textual description" of the experience. From these textual descriptions, a composite summary of the complete contextual description of the experience is developed. Moustakas describes this contextual description as:

> "beginning with the Epoche and going through the process of returning to the thing itself, in a state of openness and freedom, facilitates clear seeing, makes possible identity, and encourages the looking again and again that leads to deeper layers of meaning. Throughout, there is an interweaving of person, conscious experience, and phenomenon. In the process explicating the phenomenon, qualities are recognized and described; every perception is granted equal value, non-repetitive constituents of the experience are linked thematically, and a full description is derived. The pre-reflective and reflective components of Phenomenological Reduction enable an uncovering of the nature and meaning of an experience, bringing the experiencing person to a self-knowledge and a knowledge of the phenomenon" (Moustakas, 1994).

The *Imaginative Variation* follows as the next process after the *Phenomenological Reduction* in a phenomenological research study. The aim of the *Imaginative Variation* is to "arrive at structural descriptions of an experience, the underlying and precipitating factors that account for what is being experienced" (Moustakas, 1994). It is the description of the essential structures of the phenomenon; how the experience came to be what it is.

For the first time in the phenomenological research approach, the researcher can step back from only focusing on the experiences and facts of the experiences. The researcher can now identify and reflect on the many possibilities to derive possible structural themes for the textual descriptions. The *Imaginative Variation* culminates with the formation of a "composite structural description" of the experience through integrating the individual structural descriptions together.

The last process is the *Synthesis* of the meaning and essences of the experience. It integrates the "composite textual description" and the "composite structural description" to create a thematic description of the essences and structures of the lived experience (Starks & Trinidad, 2007). The essences and structures are described such that the experience would not be what it is without their presence.

These four processes create the analysis framework in this phenomenological study. The end result is a thematic description of the structure of the ways the PBL curriculum influences the student development of professional competencies. The thematic description will be used in Chapter 9 to help provide an explanation of how students experienced the curriculum in relation to the results from Chapter 7.

Central to creating this thematic description for the structure of the student experiences is the collection of data for analyzing the student experience. An interview is the primary phenomenology method for collecting this data (Merriam, 2009; Moustakas, 1994). The interview instrument and methods development for the quantitative study will be described in Section 8.2 and 8.3.

8.2. QUALITATIVE STUDY DEVELOPMENT

DeMarrais (2004) defines an interview as, "a process in which a researcher and participant engage in a conversation focused on questions related to a research study." The goal for the conversations, in this study, is to understand how students experienced the development of professional competencies for both importance and performance.

Since the data sought in the interviews is specific to the professional competency development, and interviewees need the flexibility of more open-ended questions, allowing the students to express their experiences in their unique ways, a semi-structured interview was conducted (Merriam, 2009). The questions were developed in advance to evoke the interviewees to provide a comprehensive description of their experience.

The interview protocol for this research study was developed with an introductory question (Kvale & Brinkmann, 2009) that not only served as an ice-breaker (Creswell, 2014) in getting participants to warm up to the interview process, but it was also used to develop a definition of professional competencies by the interviewee (Merriam, 2009) that could be used later to frame the questions on how professional competencies develop. It creates a "common language" or terminology between the participant and the interviewer to improve the clarity and understanding of the interview questions and discussions that follow. This initial question also helps to create a meditative activity aimed at setting the context for the interview and also creating a more relaxing atmosphere (Moustakas, 1994) for the interview questions to follow.

The introductory question developed was, "Which professional skills are important for an engineer?" with the planned follow-up probing questions, "Why [are they important]?" This follow-up "why" question was added to prompt additional insight (Merriam, 2009) into not only what professional skills the student feels are important, but to understand how he or she came to that determination. Given the significance of this opening question, an additional follow-up question was developed and used when needed: "Have you thought about <time management, personal responsibility, professional responsibility, communication, teamwork, …> ?" where one or more of the professional competencies was mentioned if the interviewee could not list many or any professional competencies.

The second question was an experience question (Merriam, 2009) where the interviewee was asked, "When and where did you learn the importance of professional skills for an engineer?" This question was focused on understanding the apparent development of the importance for professional competencies prior to the students starting the upper-division program, identified in the quantitative study.

This question was intended to confirm that finding and to understand the experiences that caused the development of the importance.

The next two questions were developed as a probing (Merriam, 2009) set of secondary questions (Kvale & Brinkmann, 2009) as follow-up to the introductory question. They provided students an additional opportunity to identify professional competencies. Each question had the two follow-up questions in case the interviewee gave short answers to the initial question.

- Which professional skills are your strongest? Why? Please give an example of each.
- Which professional skills do you need to keep developing? Why? Please give an example of each.

It was critical to establish what each interviewee identified as professional competencies in order to better prepare them to answer the question explaining how they experienced their development of the professional competencies. These two probing, secondary questions were originally at the end of the interview; but through the use of a pilot interview (Merriam, 2009), in the protocol development, the need to move these questions to this point in the interview was identified.

The last two questions are experience questions that specifically probe how the interviewees experienced developing the ability to perform the professional competencies they had identified earlier in the interview. The first question starts out to identify general themes for the student experience. The second question focuses specifically on the PBL curriculum experience and determines if the students identify the curricular elements developed in Chapter 5. Both questions sought to determine whether the development of the professional competencies was described in a way that confirmed the process of professional identity and competency development from Chapter 5:

- Describe how you experienced the development of your ability to perform professional skills.
- Thinking back specifically on your experience in the PBL program, which elements of the PBL curriculum caused growth in your professional performance ability?

An interview protocol was developed and used during the interviews to guide the process and provide a place for recording brief notes during the interview (Creswell, 2014). The interview protocol for the interview is found in Appendix H.

8.3. QUALITATIVE METHODS

The interview protocol was first evaluated with a pilot interview as a critical step in evaluating questions and making any necessary adjustments to the interview protocol (Merriam, 2009). The pilot interview was conducted with an interviewee who was a recent graduate of the PBL program. The primary adjustment to the protocol was changing the order of the questions, as identified earlier.

The interviews were conducted with 18 total interviewees, including the pilot interview, who were recent graduates or near the point of graduation from the PBL program. Each interview was audio recorded for later transcription along with brief notes taken by the interviewer (Creswell, 2014). A backup recording device was utilized in the event that the primary audio recording device did not function properly. The researcher and a graduate student familiar with the project work conducted the interviews. Verbatim transcriptions of the audio recordings were made to create the best database for analysis (Merriam, 2009). 185 pages of transcription were generated for this study. An individual not associated with the study completed the transcriptions.

Analysis of the transcriptions followed the phenomenological process from Section 8.1. The *Phenomenological Reduction* initiated with a simple coding process to identify and list the horizons, the key words, phrases, and expressions (Merriam, 2009; Moustakas, 1994) in the student responses, through a simple word and phrase count. This was first done with a manual counting approach to analyze the interviews and get an initial overall essence of the student experience. The interviews were listened to multiple times and the transcriptions read several times to become familiar with language and phrases used by the students (Holloway, 1997; Hycner, 1985).

The phenomenological reduction process was completed through analyzing each student interview transcript using the node analysis feature of the software package NVivo. First, all 18 transcriptions were imported into NVivo. Then a unit of meaning (node) was applied to each student statement, which was relevant to the research questions.

The *Phenomenological Reduction* was continued to determine the invariant constituents. Each of the nodes or units of meaning was tested for two requirements:

1. "Does it contain a moment of the experience that is necessary and sufficient constituent for understanding it?
2. It is possible to abstract and label it? If so, is it a horizon of the experience?

Expressions not meeting the above requirements were eliminated. Overlapping, repetitive and vague expressions were also eliminated or presented in more exact descriptive terms. The horizons that remain were the invariant constituents of the experience" (Moustakas, 1994).

122 nodes or potential units of meaning relevant to the research question were identified. The frequency varied from being mentioned by one interviewee up to being mentioned by all 18 of the interviewees. These nodes were placed into initial categories of 1) professional competencies, 2) experiences for developing importance for professional competencies, 3) experiences for developing ability to perform competencies, and 4) PBL curricular elements that developed performance ability. These categories reflect the research questions and the interview protocol.

Eliminating overlapping, repetitive, and vague expression within the categories reduced this to 102 units of meaning, which formed the invariant constituents of the experience. These non-redundant (invariant constituents of the experience) horizons or core units of meaning were then "clustered" into central themes. This process included an iterative back-and-forth approach between the interview transcriptions and the non-redundant units of meaning (Hycner, 1985).

Each interview transcription was analyzed with the central themes as new nodes in a second node analysis using NVivo. A validity check was completed at this point in the process to determine if the essence of each interview was captured with the common themes (Hycner, 1985). From this second analysis, the central themes for each category were separated into two groups:

- Common themes: central themes common to all or most of the interviews and
- Unique themes: central themes unique to single or a minority of interviews (Hycner, 1985)

The *Phenomenological Reduction* for this study was completed by organizing the themes into a coherent "textual description of the experience." How the experience came to be will be formed in the *Imaginative Variation* as "composite structural descriptions" formed from the *Imaginative Variation*. The discussion of each category will conclude with a *Synthesis* to create a thematic description of the essences and structures of the PBL curricular experience lived by the interviewees.

8.4. QUALITATIVE RESULTS

Analysis of the data yielded qualitatively different characteristics of the student experience in the development of professional competency within each of the following four categories:

1. professional competencies,
2. experiences for developing importance for professional competencies,
3. experiences for developing ability to perform competencies, and
4. PBL program elements that developed performance ability.

These characteristics describe and develop understandings of the ways in which students experienced the development of professional competencies through the PBL curriculum. The characteristics are referred to as themes. Some of the themes are common to a majority of the students and others are unique to a smaller portion of the students. Each theme reflects a qualitatively different way of understanding the student experience in the development of professional competencies. Students are not assigned to a theme, but their individual experiences are extracted to identify the themes.

8.4.1. PROFESSIONAL COMPETENCIES

The student ability to identify and describe professional competencies is important in understanding the level of knowledge students have of them. The analysis of participant responses to the professional competency definition questions also adds to the credibility of their experiences' further applicability to the research questions. Participants identified 27 different competencies as important to the profession of engineering. Participants identified these through the questions of which professional competencies they believe are important to engineering, which are their strongest, and which they need to keep developing.

All 18 participants identified the professional competency of communication extensively. It was referenced as an important competency 48 times in general, in verbal form, in written form, or in a presentation mode. In addition to communication, the common themes, mentioned by a majority of students, identified as professional competencies by the students are:

- Teamwork
- Leadership
- Professional language and behavior
- Professional dress
- Interpersonal skills
- Time management

Creating a composite textual description for this category includes reflecting back on the professional competencies of focus in this study. These common themes can each be placed within one of the three professional competencies. Teamwork and leadership fit within "an ability to function on multi-disciplinary teams" (3.d). Professional language and behavior, dress professionally, and time management fit within "an understanding of professional and ethical responsibility" (3.f). Communication and interpersonal skills fit within "an ability to communicate effectively" (3.g).

In addition to the common themes, there were eight unique themes mentioned by interviewees. They are combined with the common themes to form Table 8.1 of the interviewee themes categorized by the three professional competencies used in this study.

Table 8.1. Professional competency themes

	An ability to function on multi-disciplinary teams	An understanding of professional and ethical responsibility	An ability to communicate effectively
Common Themes	• Teamwork • Leadership	• Professional Language and Behavior • Dress Professionally • Time Management	• Communication • Interpersonal Skills
Unique Themes	• Situational Awareness	• Being Ethical • Inclusiveness • Organization • Respect • Safety	• Situational Awareness

Synthesis of Professional Competencies

The professional competency themes for the interviewees establish that their composite description of professional competencies aligns with the professional competencies used in developing the study. It creates a reasonable expectation that as participants further discuss professional competencies, they are in a thematic sense referring to the same professional competencies used in the development of the study. Therefore, as the meanings and essences for participant experiences are developed in the remaining three categories, they will be considered to apply to the student professional competencies in a thematic sense.

8.4.2. EXPERIENCES FOR DEVELOPING IMPORTANCE FOR PROFESSIONAL COMPETENCIES

The phenomenological study is intended to develop an understanding of the characteristics of the composite student experience as it relates to developing the importance for professional competencies. Specifically, it is desired to understand when and where they experienced the development of their importance for professional competencies to help explain why they did not identify growth for this in their upper-division experience.

The interviewees identified a variety of experiences for when and where they learned the importance of professional competencies for being an engineer. Experiences both in and out of the educational setting were identified. The experiences were from all phases of life from early childhood up to, and including, the last semester of their PBL education. The majority of the experiences occurred prior to the PBL curriculum. This forms a common experience for the interviewees that their importance for professional competencies was established prior to beginning the PBL curriculum. This supports the findings of the quantitative study.

Further analysis of this theme identifies that the most common sub-themes are the educational experiences in their undergraduate curriculum and experiences outside of the educational setting. The undergraduate curriculum theme was centered on working in teams and project work in the team setting. Common themes for experiences outside of the educational system include: work, family, sports, observing others, and life-long experiences. The work experience included general jobs unrelated to engineering and jobs related to engineering such as co-ops or internships.

The individual development of the above-mentioned concepts are described well by this series of quotes:

- "*They (importance for professional competencies) kind of just come slowly into your life*" [Participant C],

- "*Definitely interactions with family members, way that you act toward your family is one personal example, the way that an individual is raised I feel has a fairly large impact on how they act professionally, especially in the formative years, through high school to … beginning of college*" [Participant R],

- "I *picked that up probably when I first started working*" [Participant G],

- "*In my first internship actually… you don't realize they're important until you're not good at them. It's like, well I should've practiced that a little bit more, so… The first time was actually in the internship where you're actually working with people, professionals in your field, and you realize that they got something that you're supposed to have and so that's when you realize that it's actually important to learn them.*" [Participant I],

- "*Work I would guess, but sometimes working in a fast food restaurant people aren't (professional), depends on the person that you are, your level of professionalism and respect towards other people. At home,* *my parents are really professional teachers I guess in high school, growing up, … they were always professional*" [Participant G],

- "*It started more (or) less when I started working at the age of 14, but it was more pronounced when I started (lower-division program), the engineering program where (instructor) went into telling us that we're going to be engineers and these are the aspects that were expected of us*" [Participant Pilot], and

- "*Starting in my education through (lower-division program) was definitely the first instance where I really was able to at least see the importance of that type of a skill set*" [Participant R].

A little more than half (10) of the interviewees mentioned that the upper-division experience increased their importance for professional competency. However, they primarily identified this as a continuation of the development process for importance as summarized in these quotes,

> "*Iron Range Engineering takes that another step further where that entire project is for a client, kind of upping the professional requirements and then going through and explaining more why professionalism is so important"* [Participant R], and,
>
> "*It's very often the failures that really stand out in memory, what really makes you remember that professionalism is important. One of the largest ones was through a large project, the ____ project, it wasn't as successful as I, as I'd liked. It was very, it was definitely successes learned there through learning how important professionalism is, the communication, task orientation, the overall drive. That was a huge, huge project that uh, where I learned how important that really was and it was, it didn't perform to the level that I would've liked or expected because of the, because of that barrier, that learning curve that occurred with everyone tried to become, learning that professionalism and having those skill set at the beginning of the project*" [Participant Q].

Synthesis of Developing Importance for Professional Competencies

The essence for the experience of developing the importance for professional competencies can be characterized as being established over the entire student lifetime and academic career. The importance is primarily established prior to the start of the upper-division program. The importance is developed through experiences both within and outside of the educational process. The identified influence of an upper-division program is in the mode of either confirming or continuing to establish the importance that was already developed prior to starting the program. This affirms what was identified in the quantitative study.

8.4.3. EXPERIENCES FOR DEVELOPING ABILITY TO PERFORM PROFESSIONAL COMPETENCIES

In this category, the descriptors of how the students experienced the PBL curriculum are identified in order to develop the characteristics of how they experienced the development of the ability to perform professional competencies. It is not focused on the curricular elements; but instead, it is focused on identifying the characteristics of the development process experience. Analysis of the interviews revealed four common core characteristics:

- Reflective process
- Self-identifying improvement plan
- Cyclical – continuous improvement process
- Positioning ones' self in professional performance expectations

Reflective Process

Participants described their experiences of development as a reflective process. The development of the student ability to perform professional competencies was described as occurring through their self-evaluation of their professional competency performance as they reflected back on an experience in the PBL curriculum. The reflective self-evaluation moments resulted from the completion of a project, a team experience, or from the feedback from a peer or staff member. A student statement affirms this: "*then I found that that didn't always work out. So I guess I thought about what could I do better here*" [Participant A].

The act of reflecting was a strong motivational force in their development process, "*reflecting on how you did and how you can improve, you're only going to get better*" [Participant O]. A student description of the learning opportunities in the program:

> "*gave the opportunity to look back and reflect on what has been done and what could have been done better. That's fairly specific towards each individual project and then also along with that the professional development plan or professional improvement plans that we did every semester at IRE were kind of a culmination of those alongside what we were doing in classes and ultimately that professional development plan was the reflection on what am I doing to be professional, what can I do better*" [Participant R].

The repeated practice of the reflection process helped develop an important part of the growth process for the student and the next descriptor of self-identifying improvement plan. The students' initial steps of incorporating reflection into how they (the students) operate is representative of the following quotes:

- "*I tend to just always think of the things that I can improve upon*" [Participant A].
- "*your own self-reflection and metacognition, taking the time to sit down and really think about what you're doing, how, how [sic] it has affected you, how effective you were at doing something, and then just deciding, or determining where the gap was or if there was a gap and then what you need to do to improve on that*" [Participant I].

Self-Identifying Improvement Plan

Students describe the need to self-identify improvement areas as a way to build upon their reflection process to move forward and engage in learning activities that provide development in the professional competencies needing improvement. It is described as both the process of identifying competencies needing improvement and then developing a plan for opportunities for improvement. This is characterized in the following quotes:

- "*You can reflect on it, but if you don't implement what you reflect, it kind of just gets pushed away in the back part of your brain and you might look back someday and be like, hey yeah, I was going to do that*" [Participant Pilot].
- "*taking the time to sit down and really think about what you're doing, how, how it has affected you, how effective you were at doing something, and then just deciding, or determining where the gap was or if there was a gap and then what you need to do to improve on that*" [Participant I].
- "*one other thing I learned at IRE is, is the need to seek out opportunities. A couple of different types of opportunities I found is ones that are handed to you or set out in front of you, and other opportunities that you create yourself and really, with what you do you can generate a lot of your own opportunities for growth*" [Participant I].

Students express that the experience of self-identifying their individual development needs and an associated improvement plan must be completed more than once in the process of developing a competency. This repetition of the improvement process is the essence of the next descriptor: a Cyclical–Continuous Improvement Process, as represented by the following quote:

"*To start out, you start by assessing where you are on a certain criteria and you're given examples of what, of each, you rate yourself, give some of your strengths and weaknesses, and then start developing an action plan to, to improve those weaknesses and then, then from there on after that first semester it's just a reiteration of did you improve on your weaknesses, what do you think might have worked or might have went wrong and then just what can be improved for the next semester, and so on and so forth. Some good really comes out of it. Some of the students hate, myself included, sometimes hate doing the writing of it, but it's, I believe it's a good process and…* [Participant E].

Cyclical – Continuous Improvement Process

The students collectively identify the process of reflecting and identifying an improvement plan as part of a cyclical process of continuous improvement:

"*Your first semester you get everything thrown at you, you just try and do it best you can, but then next semester you already know every, you already know it so then you're trying to improve on what you didn't do last semester. So now, you keep improving back and forth. Like I've been improving on what I did last semester so if, as long as you continuously improve, that right there is a good process to have.*" [Participant N]

It's not just a process; it's an experience that changes the way students view their development of professional competencies. "*I didn't care what grades I got when I was at IRE. I cared that I was making positive progress towards becoming a better engineer*" [Participant C].

As students complete the program, the cyclical–continuous improvement process and the growth becomes more explicit to them as expressed by this student, in regards to leadership in a team:

"*the first semester was just identifying what my weaknesses, what my weaknesses were within leadership and then the second semester I kind of looked for areas where there were good leaders so between different teams, maybe just see how they, how their team leaders were acting, maybe look or talk to a few people about what a good leader was versus a bad leader and then last semester is the one when I started taking on a little bit of leadership roles by leading conversations or idea generation sessions, making myself more outspoken during conversations with teams, with our team I guess. And then, like I said, then the final step was actually take that leadership role and act as the leader overall and work on everything I'd seen through the last three semesters and make a good team leader*" [Participant F].

The Reflective Process, the Self-Identifying Improvement Plan, and the Cyclical–Continuous Improvement Process are the common core themes identified by the majority of participants. These themes represent what students all identified as part of the experience of developing professional competencies. There are also several other less common themes expressed by the participants. A group of these themes relates to the three common themes as they relate to students positioning themselves in regards to the expectations for professional competencies.

Positioning Ones' Self within Professional Performance Expectations

Analysis of the interviews revealed this group of themes, listed below with representative quotes. Individually they do not create a core theme, but their collective presence is synthesized into a fourth common theme of Positioning Ones' Self within Professional Performance Expectations. They represent the collective experiences that the participants went through to position themselves relative to expectations for performing professional competencies such that they can reflect, identify a self-improvement plan, and complete the cyclical-continuous improvement process.

- <u>Experienced a Culture of Professional Expectation</u> – the cultural expectation experienced by the participants caused them to genuinely become aware of their ability to perform professional competencies. It created a base foundation for students' value in developing their ability to perform the competencies.

  "*it's structured as though it were work. It's structured as if you are actually in the professional environment that you're being prepared for so because of that you have an ability to put things you learn into practice right away. And I think that was probably the biggest thing that could've helped was the ability to have that quick turnaround to put things into practice*" [Participant D].

- <u>Comparison Process</u> – participants positioned themselves relative to others' professional competency through observation of their ability to perform the competencies and through their individual awareness of the overall expectations for professional competency performance.

  "*being around people that, that maybe that are professionals. And seeing how they act and try to carry yourself in that kind of way, so being exposed to a lot of those, those kinds of people...*" [Participant E].

  "*I think the dress code is nice because it gets you aligned of how you should dress regularly*" [Participant N].

- Feedback on their performance – the experience of feedback provided participants with an external perspective that aided them in positioning (calibrating) themselves.

  "*I do like getting the feedback, because then it does help you to know where you're going and calibrate yourself ..... it's still good and it pushes you to, to work on things you might not want to*" [Participant M].

Synthesis of Experiences for Developing Ability to Perform Professional Competencies

Synthesizing the four common themes together forms a thematic description of the participants' experiences. As they progress through the PBL curriculum, they experience a cyclical process of continuous improvement in their ability to perform professional competencies. In this process, the individual abilities to perform these competencies are positioned relative to expectations of both the program and the profession. As participants reflected on their position in their ability to perform, they expressed that growth came from self-identifying an improvement plan to improve their performance and completing the improvement work in the next project cycle of the program.

For some students, this was a gradual continual process that was part of their experience from the beginning of the program. About half of the students identified that this process had a more abrupt start that began with a significant defining moment, which caused them to realize the need for developing their performance of professional competencies. The next category continues to explore the student experience through identifying which of the elements of the PBL curriculum generated these experiences and developed the student ability to perform professional competencies.

8.4.4. PBL CURRICULAR ELEMENTS THAT DEVELOPED PERFORMANCE ABILITY

Students identifying PBL curricular elements, as part of their experinces, is an important part of explaining how the PBL program developed the student ability to perform professional competencies. Analysis of the interviews revealed three common characteristics of the student experience description for the PBL curricular elements:

- Industry Projects
- Learning Activities
- Program Culture

Industry Projects

Participants described the work related with the industry project as the most common theme of any influence in developing their ability to perform professional competencies. The aspect of working on a real industry project made the learning of the professional competencies much more valuable to the participant. Three key sub-themes were identified for the industry project work:

- Activities to Complete Project – Participants identified the work associated with the completion of the industry projects as an experience that not only required them to use their professional competencies but also did so in a genuine fashion that made the competencies real to the students and their team members. This theme is represented by: "*I think the experiences that caused the most growth were actual projects. It's one thing to sit in the workshop and be told you know, this is what good looks like, this is what we do, but then it's another to actually implement that and put it into practice*" [Participant D].

- Interaction with Project Client – a key sub-theme for the industry projects was the interaction with a project client from the sponsoring industry. The credibility that the client had in regards to the value of being able to perform professional competencies was substantial. In the words of a few participants:

  "*teaching them what industry is almost going to be like, you know you're going to need to present yourself in a professional manner, you are going to be held to higher standards, you are responsible for real items that you need to report back to real people in the world. They're not just, you know, make-believe things in a book or something like that*" [Participant F].

  "*the biggest one for me is the external clients, meeting with them, requires professional communication through email, uh, showing up to meetings, and meeting with them I guess involves professional skills, and then having that standard of these are companies in industry that you might possibly work for in the future or use as a reference, really sets like a high standard for professionalism, which I guess gives you an idea of what's going to be expected when you're actually employed as an engineer so. It's, I'd say that's probably the most important aspect of professionalism at IRE is the external clients*" [Participant O].

  "(*the PBL program) takes that another step further where that entire project is for a client, kind of upping the professional requirements* *and then going through and explaining more why professionalism is so important* " [Participant F].

- <u>Working on Teams</u> – When answering how they developed the ability to perform professional competencies, participants generally would use the experience of working on as team as the context for their responses, such as:

  "*I would say again that having the opportunity to work on teams*" [Participant K].

  "*just our project teams, you know, every semester we're, we're doing real work, so it's giving us real experience, you know, requiring real skills that, that we're using on a everyday basis*" [Participant K].

  "*I feel like a part of the whole team and I feel like someone, somewhere is looking out for me and someone, someone, somewhere just wants me to succeed. So just that small setting made my professional responsibility, I felt like I was, I was improving because I constantly had feedback and it worked on the feedback to be a better person*" [Participant H].

  "*makes you engaged, you know, just working with other team, other team members. You grow up, you're growing up in the skills communicating and the same time growing up in skills of working on a team, in a team at the same time, you have your own weaknesses in the project you know. You're not perfect, but then just the fact that someone else can see, your struggles and they will try to help you through the struggles, improve your skills of learning, so it makes you more engaged and at the same time this really translate, the projects really translate to the real world"* [Participant H].

  "*I would say the biggest takeaway is just being on that team. I had, I've had some experiences just meeting with team a couple hours a week to build something or to work on a report, but nothing quite to this scale, which is more realistic where you have a team that you're with, I mean eight hours a day*" [Participant L].

  "*even the fact that no team is perfect, when you, when there's more than one person trying to get something done there's going to be some conflict. So definitely… conflict resolution, small or big scale is huge, getting some experience with that now and learning how to deal with that and even the awareness of it is huge*" [Participant L].

The industry projects serve as the integral part of the student experience. "*They have you engaged throughout the whole semester, working on the project, working with other people, (and) working with clients. You know, it just teaches you a lot of professional (competencies).*" [Participant H] They are the primary curricular experience identified as a core theme that students attribute to their development of professional competencies.

Learning Activities

In addition to projects, participants listed other learning activity elements of the PBL curriculum that they identified as part of their experience in the development of the ability to perform professional competencies. Three key sub-themes emerged in the analysis of the interviews:

- Workshops and Seminars – a signature experience of the PBL curriculum that students identified is the weekly professional development seminars and the periodic professional development workshops. Students identified that these two learning activities were where they became aware of how they could better perform professional competencies. They identified best practices for them. Other experiences in the curriculum allowed the students to practice the competency and grow in the ability to perform, but the workshops and seminars served as the starting point in this development process. As expressed by a few interview participants:

  "*I guess one of the big things would be, I mean we look at all the professional development seminars we did, you know, how to be a leader, how to, what it means to be a team member, but then also being able to apply that to your personal development*" [Participant D].

  "*Attended a couple of seminars by (presenters) as to what's good presentation style, what you should do, what you shouldn't do. And then kept formulating that from there and now I've grown each semester as to refining my presenting style and I feel I'm a pretty effective presenter*" [Participant D].

  "*We have seminars where we learn a lot of this important skills. So for me personally, I wanted to exercise them in, let's say in my team or with other people, so I have reflection journals that help me write my goals and how to achieve them*" [Participant H].

  "*First it's the actual seminar itself where we are talking about the stuff we do either on your smaller teams at the seminar, doing more of a discussion and then on top of that for the most part you end up* *doing some sort of written reflection on that event and that just helps, helps, helps just make it stick a, a little more, especially if he's, as long as you're focusing on you know the key takeaways of that session*" [Participant L].

"*(seminar) kind of sets the tone for the week. It makes you, you come back from, sometimes maybe a three day weekend and then you just don't really want to be there, and then you go through your seminar, and it's like, yep, I need to get back into my professional aspect. I was maybe a lazy bum all weekend. I went out partying or whatnot and then you get there Monday and you get your dose of reality again and it was just like, ok, it's time to collect myself and get back on task and think about and evaluate what was talked about so that I can keep moving ahead on through the week*" [Participant L].

- Student Presentations – the role of extensive presentations in the curriculum was identified as a curricular element of the program that developed students' professional competencies. Specifically, the repetition of the presentations served as a model for performing, reflecting, identifying improvement opportunities, and then practicing again. The sentiment of the student responses, when asked what activities helped them to develop professionally, is summed up by Participant P's response, "*well the presentations obviously!*"

  In addition to the presentations themselves, the peer feedback process added to the value of the experience. One participant describes the cyclic curricular element as:

  "*So before I came to (PBL program) I had maybe done one or two presentations before coming there, so I was not very outspoken. I didn't really want to do public speaking or anything like that. So the very first semester I kind of was just thrown in it, and I didn't know what to do and I got some pretty bad reviews from people of what I did wrong and what I should be doing and I didn't come up with a very good plan of how to attack that right away so I just… The first semester, wrote down what I did bad, you know. I wasn't speaking clearly, I wasn't presenting clearly to clients or to faculty members for that, for that matter, so I made a plan of I'm going to make sure I take notes as to what other presentations are doing because we had multiple presentations at (PBL program). So see what good presentations look like between the slides, between what their hand movements are, what their eye gestures are, how they're speaking, how enthusiastic they are. Attended a couple of seminars by (presenters) as to what's good presentation style, what you should do,* *what you shouldn't do. And then kept formulating that from there and now I've grown each semester as to refining my presenting style and I feel I'm a pretty effective presenter. I have a pretty good pattern of just coming up with a basic slide deck, going through it a few times and then adding a little bit here and there and uh, presenting multiple times before actually presenting to either a client or (PBL program) or anyone like that so I'm pretty comfortable presenting to anyone now. I'm pretty outspoken with that, which I didn't think I'd do that before I came to (PBL program)"* [Participant F].

- <u>Professional Development Assessment</u> – students experienced the assessment of professional development activities in multiple ways. Some were in the context of other activities such as the feedback in the presentations. This feedback was mentioned as one of the core themes in their experiences. Participants identified two forms of professional development assessment as an important part of the curriculum in the feedback experience. One was the professional development plan (PDP) where students self-assess their ability to perform professional competencies and formulate a plan to develop the competencies most in need of growth. The second is the formal feedback from program facilitators on the same topics as the PDP. Participants referenced both of these:

  "*by completing the (PDP) you're forced to gauge your performance in each of those areas, your personal view of where you're at, and I mean depending on how you perceive yourself you can see areas for improvement, you can…if you have the desire to improve in those areas you tend to take it a little more seriously and develop a plan based on what you perceive of yourself to make it, make yourself better for the next uh, go-around*" [Participant F].

  "*I do like getting the feedback, because then it does help you to know where you're going and calibrate yourself in terms of, of that so like yellow sheets are useful. They don't always tell me stuff I didn't know, but it's still good and it pushes you to, to work on things you might not want to"* [Participant M].

The learning activities are a critical part of the formal PBL curriculum. Participants identified a wide variety of learning activities that were part of their development of the ability to perform professional competencies. The three common themes of Workshops and Seminars; Student Presentations; and Professional Development Assessment are the activities that formed the common core of the learning activities for the participants.

Program Culture

The experience of the projects and learning activities is strengthened by the overall program culture. Participants identified that the cultural expectation for professionalism combined with the cultural expectation for respectful feedback between students, as well as from staff to students, resulted in a safe learning environment where they could practice and develop their professional competencies. The practice of professional competencies becomes part of how the students conduct themselves on an ongoing basis. Participant E described the overall cultural expectation for professionalism:

> *"there's a few things that we do there that are just expected in the professional world of dress and timeliness, and to a sense I think they're good things to practice, but I don't know if dress is something, in my mind, that practice really makes perfect, it's not, anyone can dress, dress appropriately if they want to, but I think it really just sets the tone for a good professional sense in workplace, and you're just kind of... In a whole, I treat my day like, like a workday, where I show up at, I show up at 7, and I leave usually around 4 or 5 o'clock. So it just puts you in that mind of being in that professional, professional world and treated like a professional and not really talked down to like you're, like you're a child so I think it's just kind of a all-around good, good ecosystem to kind of work and grow in….*
>
> *the expectations are very high ... just like they would in the workplace, and what you can expect. So I think the model really resembles, at least from what I know of industry of what's to be expected as, as you get there, timeliness and things in that matter that I guess I probably forgot to mention in the earlier part, but they're just so, I feel with the model, they're just so kind of ingrained in me that I often maybe even overlook them so....*"

A common theme for supporting this culture is the feedback to students from their peers, their facilitators, and program staff:

> "*everything we do, or did at IRE, we had feedback on, or just about everything, whether it be peer feedback or uh (facilitators), instructors feedback*" [Participant I].
>
> *"feedback from the professors and peers on where we were lacking and what we did good helped to drive us, push us forward, and to improve"* [Participant Pilot].

Many experiences had the theme of the supportive nature of the feedback. The feedback is accepted due to the genuine belief that the feedback is meant to help and that it can be trusted within a safe environment:

> "*when you know people it's easier to receive feedback and to get good feedback. Like if you care about somebody, and you give them feedback, a lot of times it's more, more useful than if it's… a stranger and this is what I think, you know, because you know more about them. You can, you can tailor your feedback to, to be more useful and maybe even say, well when you did this other thing that I saw you do, and you were really good at that, try to do more like that. Then you know, but if it's somebody that you weren't that close to, or you didn't really know you wouldn't be able to get that kind of connection and communication and those things I think are really useful. It's not just I guess we were saying failure is one of the things that makes you grow, but it also teaches you who has got your back, and that can also be very useful in growth to have a system, a support system or people there to help you learn from your failure otherwise…*" [Participant M].

Students not only found value in what they learned from receiving feedback, but also through the process of giving feedback to their peers, "*being asked to give feedback to others. So when, when somebody asks you for feedback, and then you're critiquing them, it really thinks about how, how am I doing it, am I good at it or bad at it, am I a valid source of feedback and you start to think, when you're thinking about that, then you start to go back and develop yourself there further so you do feel credible"* [Participant I].

It is evident that there is a core theme among the participants; the program culture, with its expectation for professionalism and an expectation for supportive feedback, creates a rich environment for students to develop their professional competencies.

***Synthesis of PBL Program Elements* that Developed Performance Ability**

The combination of the three common themes of Industry Projects, Learning Activities, and Program Culture synthesizes a thematic description of the PBL program elements that collectively developed the participants' ability to perform professional competencies. As students experienced the PBL curriculum, the industry projects formed the core program element that created genuine student value and appreciation for their ability to perform professional competencies. The "real world" aspect of the work and the interaction with the industry client caused students to generate a value for professional competencies that could not be created in the academic environment alone.

The learning activities created a structure that allowed students to develop in their ability to perform professional competencies. These activities served to guide students in identifying and understanding what good professional competency practices are, how to practice them, and then provided a guided process for developing them.

The program culture creates a learning environment that is supportive of the development process of the learning activities in such a way that students are practicing the competencies on a regular basis and not “just when they have to” for the industry projects and client interactions. The PBL curricular elements create a continuous experience for the student development of professional competencies.

The overall essence of this experience is captured in: *“Having practiced it and then kind of ingrained that in you, that well everybody knows it’s the right thing to do, but then how do you effectively execute that and having practiced it, working with professionals as peers, working with professionals as instructors, working with professionals in the real world from the projects, seeing what it’s like, what you can expect and that it feels good and you can feel accomplished*” [Participant I].

8.5. INTERPRETING THE QUALITATIVE RESULTS

The qualitative study was designed to explain and to give insight as to how the students experience the PBL curriculum and how it leads to developing the student ability to perform professional competencies. Of equal interest was the understanding how students experienced the development of the importance for the professional competencies. The analysis of the qualitative results from the phenomenological study will focus on assessing how the findings answer the research questions; compare the findings back to the PBL model described in Chapter 3 and the professional competency development cycle from Chapter 5; and a reflection on the meaning of the findings (Creswell & Clark, 2011).

The analysis will be used in interpreting the qualitative results for the three sub-questions:

1. What do students define as professional competencies?,
2. What is the growth of the student professional competencies in a PBL curriculum?, and
3. What are the development experiences for professional competencies in the PBL curriculum?

to answer the primary research question “In what ways does the Project-Based Learning (PBL) Curriculum Influence the Development of Professional Competencies?”

What do students define as professional competencies?

Student participants demonstrated the ability to verbalize professional competencies at a high level. Even though students were left to self-identify the professional competencies in the interview, they collectively verbalized common and unique themes that described the three professional competencies of focus in this study:

- Teamwork and Leadership themes fit within "an ability to function on multi-disciplinary teams" (3.d).
- Professional Language and Behavior, Dress Professionally, and Time Management themes fit within "an understanding of professional and ethical responsibility" (3.f).
- Communication and Interpersonal Skills themes fit within "an ability to communicate effectively" (3.g).

Not only were students able to describe, or define, these competencies, they also demonstrated the consistent ability to self-evaluate their ability to perform them. They could articulate which were their strongest competencies and why, but they could also articulate the competencies that needed continued development and could articulate why they knew and how the competencies could be developed.

Looking back on the PBL curriculum and the professional competency development cycle, the ability to verbalize the professional competencies results from the process of explicitly and repetitively using the language of these professional competencies and making them an explicit learning outcome of the program for students. The development of student understanding of the professional competencies takes place in the reflective process of the semester-long professional development cycle. An important influence in this process are the industry projects and the interactions with the project clients from industry.

What is the growth of the student professional competencies in a PBL curriculum?

The second sub-question, regarding the growth of professional competencies, is the primary focus of the quantitative study. The qualitative analysis explains how the students experienced the growth in importance for and performance of professional competencies.

The synthesis of the participants' experience in developing importance is that it was developed over their lifetimes, primarily prior to upper-division. This concept helps explain the high levels of importance for professional competencies for both groups in their pre- scores with no significant growth during their upper-division program. The PBL participants' experience had the theme that the curriculum reinforced: the importance which had been established in prior experiences.

In the growth of performance, qualitative study participants could identify common themes for their development. Overall the growth process was described as a cyclical process of continuous improvement. This is a direct reflection of the professional competency development cycle in the PBL curriculum.

What are the development experiences for professional competencies in the PBL curriculum?

The third sub-question, concerning the student PBL curriculum experiences in the development of professional competencies, is the primary focus of the qualitative study. It is anticipated that understanding the student experiences will help explain the development of the participants' ability to perform professional competencies.

The common themes identified by the participants as their experience for developing the ability to perform professional competencies are:

- Reflective Process
- Self-Identifying Improvement Plan
- Cyclical – Continuous Improvement Process
- Positioning Ones' Self in Professional Performance Expectations
    - Experienced a Culture of Professional Expectation
    - Comparison Process
    - Feedback on their performance

Connecting this back to the IRE Professional Competency Development Cycle, the reflective process is a part of each stage and the overall cycle. It is a purposeful part of the cycle that each stage has a reflective process as part of the curriculum. The self-identifying of an improvement plan is a critical part of the process for students identifying their growth areas for professional competencies. It is part of the development cycle in the anticipatory and personal stage. It is purposefully accomplished though the professional development plans, as well as through many informal opportunities.

The cyclical nature of the curriculum was identified in the study as being a cyclical-continuous improvement plan. It is a direct result of the intended PBL curriculum design to provide students with repeated exposure to developing the professional competency outcomes. Throughout these experiences, students identified different ways in which they experienced positioning themselves relative to professional competency performance expectations. Their developing awareness of the expectations for professional competency performance was supported by the expectations of the PBL curriculum culture. It was developed as the students went through a cyclical process of positioning themselves relative to the observed performance of other students, faculty, and project clients. Their observations were also reinforced by the feedback, which they received on their performance through structured activities in the program.

The other category for answering the third sub-questions is the PBL curricular elements which the participants identified as common themes for developing their professional competency performance ability. Students identified Industry Projects, Learning Activities, and the Program Culture, with their associated sub-themes in Table 8.2, as the curricular elements that developed the learning experiences, which they identified for developing their professional competency performance.

Table 8.2. PBL curricular elements

Industry Projects	**Learning Activities**	**Program Culture**
• Activities to Complete Projects • Interaction with Project Client • Working on Teams	• Workshops and Seminars • Student Presentations • Professional Development Assessment	• Program Expectations for Professionalism • Feedback • Supportive Environment

These elements connect the student themes back to the IRE Professional development cycle as they form the base structure upon which the cycle is based. Looking back to Chapters 3 & 5, the curricular elements not identified directly by the participants are the role and value acquisition and the associated identity development process. A future improvement in the IRE PBL curriculum is to make them more visible to students.

At this point, the reflection on the meaning of the findings, will be through my list of preconceptions and prejudgments of the experience, developed as the researcher, for the bracketing process:

- *Professional development is a cyclical experience, Sheppard et al. (2009), and must take place over multiple experiences:* Participants did identify the cyclical process and the need for multiple experiences through a continuous improvement theme.
- *For the development process to be effective, it must be guided by the faculty:* Although not developed as a common theme, participants did recognize or refer to the role of faculty and the facilitators in

developing the culture and learning experiences for developing professional competencies.

- *Professional/project practice or experience is necessary for professional development:* Students clearly identified the importance for the project and the associated professional practice as necessary for their professional development.

- *Not all competencies (or habits) are desired or positive; the desired competencies must be cultivated:* The competencies identified by participants are the ones desired in the sense that they support, or are a component of, the three competencies of focus for the PBL curriculum and this study. The professional competency cycle has developed the desired competencies, and the non-desired competencies or in-competencies were not identified by the participants.

- *PBL is an effective way to develop professional competencies:* The effectiveness of the PBL curriculum is more a part of the quantitative study, but certainly the students were able to verbalize professional competencies and their own experiences in developing these competencies at a high level. This verbalization indicates that students were certainly aware of professional competencies, and they could identify the experiences and processes for developing them. Students expressed a common theme that the program culture created an authentic environment, which was effective in developing professional competencies. Students also identified many of the inherent aspects of PBL that caused the development.

This section provides the initial answer to the primary research question. The final description of "In what ways does the Project-Based Learning (PBL) Curriculum Influence the Development of Professional Competencies?" will be the focus of Chapter 9.

8.6. QUALITATIVE STUDY QUALITY AND VALIDITY

Bernhard and Baillie (2013) proposed criteria for the quality and validity of qualitative study results in engineering education research. In this section, the criteria will be applied to the results of this quantitative study.

Quality of Results

- <u>Richness in Meaning and Structure</u> – a balance between the richness of the meaning and the structure of the results was accomplished through the phenomenological reduction and synthesis. The interpretation of the results captures the essentials of the student experience into a comprehendible description regarding developing the importance for and ability to perform professional competencies. At the same time, the use of select quotes retains the richness of the experience with the subtle nuances and unique aspects of the individual student experience.

- Contribution to Theory Development and New Knowledge – the results of this study contribute to the understanding of how students experience the development of professional competencies within PBL, specifically identifying which elements of the curriculum contributed to the student development of the professional competencies.

- Presentation of Results – the results are presented using clear and concise language that is relevant to the greater engineering education community, specifically those involved with curriculum development and continuous improvement.

Validity of Results

- Discourse Criterion – the basis for the study is the recognized need, particularly in the U.S., to develop the professional competencies of students. The literature review and the study build on the promising practices of professional practice/PBL, identity development, reflection, and an explicit focus of the professional competencies as a student program outcome. Building on the results of the quantitative study has potential for informing the greater engineering education community.

- Heuristic Value – the results of the qualitative study should cause the reader to look differently at professional competency development and the ways PBL can influence the development. The qualitative study results are supported by both the conceptual framework of the IRE PBL professional competency development semester cycle (Figure 5.1), with its intensive reflection component, and the quantitative results which found that PBL participants maintained a high level of importance for professional competencies while increasing their ability to perform. This is particularly compelling given the comparative non-PBL group showing a decrease in importance and no increase in performance.

- Empirical Anchorage - there is always the question of subjectivity in qualitative research. For this study, the quantitative results, the development of the qualitative study from them, and the direct use of quotations create a connection between "reality" and the interpretation of the results. This connects directly back to the selection of a pragmatic mixed-methods study that reflects both the post-positivist and interpretive/constructivist epistemological perspectives.

- Consistency - the development of the quantitative study and the interpretation of the results are consistent with the epistemological perspective developed through the theoretical underpinnings developed in both Volume 2 and earlier in 1. The results are connected back to the professional competency cycle in the previous section.

- Pragmatic Criterion - the qualitative results were developed for direct consideration in other engineering education settings. Chapter 9 will answer "In what ways does the project-based learning (PBL) curriculum influence the development of professional competencies?" through identifying which elements of the IRE PBL experience apply to all PBL curriculums and which are unique to this particular curriculum. PBL and the curricular elements are presented for consideration by those decision makers directly involved with curriculum development or continuous improvement.

The explicit discussion of these criteria for this qualitative study is fundamental in establishing the quality and validity of the results. This discussion is in preparation for the qualitative study summary and the research conclusions that now follow.

8.7. QUALITATIVE STUDY SUMMARY

The phenomenological study was designed and conducted to develop an explanation, or provide some understanding as to, how the students experienced the PBL curriculum and how it led to developing the student ability to perform professional competencies. It also sought to understand the student concept of developing the importance for professional competencies.

Analysis of the data yielded qualitatively different characteristics of the student experience in the development of professional competency within each of the following four categories:

1. professional competencies,
2. experiences for developing importance for professional competencies,
3. experiences for developing ability to perform competencies, and
4. PBL program elements that developed performance ability.

Summarizing the synthesis from each of the four categories creates a thematic essence of the entire PBL experience for the participants that begins with identifying the alignment between the participants' composite definition for professional competencies and the professional competencies of focus in the study from Chapter 5. With this common language established, the development of the student importance for professional competencies was established as a process, which occurred over the entire student lifetime and academic career both within and outside of academia.

Four common themes emerged as characteristics which described the way participants experienced the development of their ability to perform professional competencies: 1) Reflective Process, 2) Self-Identifying Improvement Plan, 3) Cyclical – Continuous Improvement Process, and 4) Positioning Ones' Self in Professional Performance Expectations. Some participants experienced the development as a gradual, continual process from the beginning. Other students identified that the process abruptly started for them after experiencing a significant defining moment, which caused them to realize the need for developing their performance of professional competencies.

Three common themes of 1) Industry Projects, 2) Learning Activities, and 3) Program Culture are a thematic description of the PBL curricular elements identified in the development of the participants' ability to perform professional competencies. The PBL Program elements formed a continuous experience in the student development of performance for the professional competencies.

In the interpretation of the qualitative results, the themes from the findings were connected back to and supported by the PBL curricular theory and IRE Professional Competency Development Cycle from Chapters 2.4 and 5, respectfully. The interpretation of the results will continue in Chapter 9 with the interpretation of the qualitative results converging with the interpretation of quantitative findings. Together, these interpretations will provide a rich answer to the primary research question, "In what ways does the Project-Based Learning (PBL) Curriculum Influence the Development of Professional Competencies?"

CHAPTER 9. CONCLUSION

This study of professional competency development in a project-based learning (PBL) curriculum resulted in a greater understanding of "In what ways does the project-based learning (PBL) curriculum influence the development of professional competencies?" The key findings from the quantitative and qualitative studies from this mixed-methods explanatory work are that students report:

- An ***increase in performance of professional competencies*** for participants who experienced the PBL curriculum, as compared to no increase in performance reported by participants who experienced a non-PBL upper-division curriculum.
- *The* ***level of importance for professional competencies already established prior to upper-division*** for the participants of this study. PBL participants began with and maintained a high level of importance. Non-PBL participants began with an equally high level of importance. They maintained the high level of importance in a team related context but decreased in importance for individual professional competencies.
- PBL participants are able to ***verbalize professional competencies at a high level*** and clearly describe their own professional development process.
- ***PBL curriculum experiences***, identified by participants, ***for developing performance of professional competencies***:
    - Reflection
    - Self-identifying improvement plan
    - Cyclical continuous improvement
    - Positioning themselves in the professional competency
        - Understand professional competencies expectations
        - Self-comparison – calibration
        - Feedback
- ***PBL curricular elements***, identified by participants, ***for developing performance of professional competencies***:
    - <u>Industry Projects</u>: activities to complete projects, interaction with project client, & working on teams
    - <u>Learning Activities</u>**:** workshops and seminars, student presentations, & professional development assessment
    - <u>Program Culture:</u> program expectations for professionalism, feedback, & supportive environment

- Participants ***experienced their personal commitment to professional competencies in two ways***:
    - Gradual Development – the commitment was a continuous process that started prior to or from the beginning of the PBL curriculum. The genuine engineering activities continued their development and embracement of the professional competencies.
    - Defining Moment – it was initiated by a single event or distinct series of events that created a defining moment for the participant. It started their development and embracement of the professional competencies after a personal crisis moment that was created by the genuine engineering activities.

The next section summarizes how the study arrived at these key findings.

9.1. SUMMARY OF RESEARCH

This research work initiated with the development of the Iron Range Engineering (IRE) PBL curriculum, as described in Volume 1. One of the primary motivators for the program development was the identified gap between engineering education and the current and future needs of the engineering profession. The motivation for this study was to understand better the theory regarding student development of professional competencies and to understand the ways that the IRE PBL curriculum influenced the student development of professional competencies.

The intent of the study is to provide engineering education with an understanding of how PBL can address the professional competency development needs in the U.S. engineering education system. Specifically, the study intended to provide engineering education decision-makers with descriptive data to understand how the PBL curriculum influences the development of professional competencies.

This work was completed in three main parts. Chapter 5 was the review of the literature and the development of a curricular model to meet the professional competency development need. Chapter 7 described the quantitative study of student professional competency growth. Chapter 8 developed and described the qualitative study of the professional competency development to provide a sequential explanation of the results from the quantitative study. The sequential explanatory mixed-methods study was initially developed in Chapter 6.

Literature Review and Development of Curricular Model

The literature review first focused on developing a definition for the professional competencies and an understanding of the current state of professional competency development in engineering education. The professional competency definition for the study is *the potential that students have to use professional knowledge and skills to perform in the complexity of a real-life engineering situation. The student's self-conception and motives are considered an important foundation for these competencies.* The professional competencies studied are the ABET student outcomes in Criteria 3. The criteria of specific focus are: 1) an ability to function on multi-disciplinary teams (3.d); 2) an understanding of professional and ethical responsibility (3.f); and 3) an ability to communicate effectively (3.g).

The curricular model is based on the approach of developing professional competencies through the development of the student professional identity. The student professional identity is more than just knowing professional competencies; it is the ability to create a narrative for constructing, using, and refining the students' educational and professional careers as they position themselves in relation to the profession. The identity is the base from which students act out the professional competencies.

Four core curricular elements were focused on for developing the student professional competencies through the formation of the student professional identity: 1) competency outcome-based education focus, 2) role acquisition, 3) professional practice and project-based learning, and 4) reflection. These elements are combined in the curricular design to form the IRE Professional Competency Development Cycle, shown in Figure 5.3 It is also based on the findings from Chapter 2 in regards to the curricular learning of PBL theories. The curriculum elements were specifically developed to construct the content, incentive, and interaction dimensions of Illeris's model for the dimensions of learning, as shown in Figure 5.4, to develop a student learning experience as the intersection of these dimensions.

The literature review and the development of the curricular model led to the research questions. The primary research question was "*In what ways does the project-based learning (PBL) curriculum influence the development of professional competencies?*" Answering the question took place through compiling the answers for the three sub-questions:

1. "*What do students define as professional competencies?*",
2. "*What is the growth of the student professional competencies in a PBL curriculum?*", and
3. *"What are the development experiences for professional competencies in the PBL curriculum?*"

Although the curriculum was developed through a *social constructivism* perspective, a pragmatic explanatory mixed-method research approach was selected to provide a more complete understanding of the ways the PBL curriculum influenced the student development of professional competencies. It did not focus on a single epistemological perspective for the research approach, but utilized both Interpretive/Constructivist and Post-Positivist perspectives. The study began with a traditional explanatory sequential design with the intent to focus on the results of the quantitative data and then understand them better through a phenomenological qualitative study. As the study progressed, there emerged the recognition that the quantitative and qualitative results had equal value in understanding the development of professional competencies as influenced by the PBL curriculum.

Quantitative Study

The quantitative study focused on the second sub-research question of "What is the growth of the student professional competencies in a PBL curriculum?" It looked at the student development for importance and performance for both the internal (individual) interactions and the external (team) interactions from Illeris's model. There were four directional hypotheses:

- *Hypothesis 1*: PBL students will have an increase in their self-reported importance for professional competencies.
- *Hypothesis 2*: This importance increase will be greater for PBL students than the increase for non-PBL students.
- *Hypothesis 3*: PBL students will have an increase in their self-reported performance for professional competencies.
- *Hypothesis 4*: This performance increase will be greater for PBL students than the increase for non-PBL students.

Two instruments were developed to evaluate the professional competency development of students in the PBL model as compared to students studying in a more traditional model. The first instrument, the *Individual Professional Competency Instrument*, focuses on the individual professional competencies emphasizing the internal or individual interactions. The second instrument, the *Team Professional Competency Instrument*, focuses on the student professional competencies for external interactions, specifically in the team context. Both instruments evaluated student importance and performance.

The two instruments were utilized to make four comparisons (individual importance, individual performance, team importance, and team performance) within each group Pre- to Post- and through group-to-group comparisons at the pre- and post- stages for a total of 16 comparisons. Findings of interest from the comparisons are:

- Non-PBL has a higher pre- composite for *Team Performance* as compared to PBL

- Non-PBL has lower post- composite score in *Importance* for both instruments
- Non-PBL reduces in *Importance* (pre- to post-) for *Individual* instrument
- PBL increases in *Performance* (pre- to post-) for both instruments
- PBL has no change in *Importance* (pre- to post-) for both instruments. Scores start and stay at a high level.

The quantitative results indicate probable support of hypothesis 3 and hypothesis 4 but not for 1 and 2. The first aspect of the qualitative study was to gain an understanding of why the students in the PBL group did not show the expected increase in the importance for professional competencies, as proposed in hypotheses one and two.

Qualitative Study

The second aspect of the qualitative study was to gain an understanding of the student experience and also identify which elements of the PBL curriculum affected the student professional competency development experience. This aspect will provide further explanation and understanding of the promising quantitative study results.

The qualitative study focused on the interviews of 18 PBL participants, utilizing a phenomenological approach, to develop an understanding as to how the students experienced the PBL curriculum and how it led to their developing the ability to perform professional competencies. It also sought to discover an understanding of the process for the development of their importance for professional competencies. In addition, the qualitative study sought to answer the first and third sub-research questions.

Analysis of the data yielded a synthesis for participant experiences within four categories:

> <u>**Professional Competencies Definition**</u> The themes for defining professional competencies create a comprehensive definition and demonstrate a strong understanding of professional competencies and awareness for their personal level of competency.
>
> <u>**Experiences for Developing Importance for Professional Competencies**</u> It is clearly indicated that the importance for professional competencies was established prior to upper-division at a high level. The PBL curriculum confirms and maintains the importance. The traditional curriculum does not confirm nor maintain the importance.
>
> <u>**Experiences for Developing Ability to Perform Competencies**</u> Four common themes describe the participants experience in developing their

ability to perform professional competencies in the PBL curriculum: 1) Reflective Process, 2) Self-Identifying Improvement Plan, 3) Cyclical – Continuous Improvement Process, and 4) Positioning Ones' Self in Professional Performance Expectations. Some experienced the development as a gradual and continual process while others identified the process abruptly started for them with a significant experience, a defining moment.

PBL Curricular Elements that Developed Performance Ability Three common themes for the curricular elements that the participants identified for developing their performance ability for professional competencies: 1) Industry Projects, 2) Learning Activities, and 3) Program Culture

Summarizing the synthesis from each of the four categories results in a thematic essence of the entire PBL experiences. This synthesis indicates a cyclical process of exploration and reflection that develops the student professional identity and the performance ability for professional competencies.

Answers to Research Questions and Integration of Findings

The primary research question was "In what ways does the Project-Based Learning (PBL) Curriculum Influence the Development of Professional Competencies?" Answering the question took place through bringing together the answers for the three sub-questions:

1. "What do students define as professional competencies?"
2. "What is the growth of the student professional competencies in a PBL curriculum?"
3. "What are the development experiences for professional competencies in the PBL curriculum?"

Sub-Question 1: "What do students define as professional competencies?"

Understanding how students who experience the PBL curriculum define professional competencies was a focus of the qualitative study. Through the phenomenological approach, the answer to this question was developed as student participants verbalized common and unique themes, which collectively describe and define the three professional competencies of focus in this study:

- The common themes of teamwork and leadership, along with a unique theme of situational awareness, describe **an ability to function on multi-disciplinary teams (3.d).**
- The common themes of professional language and behavior, dress professionally, and time management, along with the unique themes of being ethical, inclusiveness, organization, respect, and safety,

describe **an understanding of professional and ethical responsibility" (3.f).**

- The common themes of communication and interpersonal skills, along with the unique theme of situational awareness, describe **an ability to communicate effectively" (3.g).**

The results indicate that the students have developed a comprehensive understanding and definition of professional competencies. Not only were students able to describe, or define, these competencies, they also demonstrated a consistent ability to self-evaluate their abilities to perform them. The students could articulate which were their strongest competencies and why. They could also articulate the competencies, which needed continued development and could articulate why they knew, and how these competencies would develop. The participants' established abilities to define professional competencies create a reasonable expectation that the remaining discussions of professional competencies are, in a thematic sense, referring to the same professional competencies used in the development of the study.

Sub-Question 2: "What is the growth of the student professional competencies in a PBL curriculum?"

The growth of student professional competencies was a focus of both the quantitative and qualitative studies. The quantitative study indicates that students *do not develop an increase in their importance for professional competencies*; however, the students *do develop an increase in their performance* for professional competencies. The growth in performance for the PBL group was greater in comparison to the non-PBL group who showed no growth in their performance. The students' importance for the professional competencies started high and stayed high for the PBL group as they experienced their upper-division PBL curriculum.

The qualitative study explains that the PBL students developed their concept of the importance for professional competencies over their lifetime, both outside of and within educational settings, but prior to upper-division. The PBL participants' importance for the professional competencies was reinforced as they experienced the PBL curriculum.

Sub-Question 3: "What are the development experiences for professional competencies in the PBL curriculum?"

This question is the primary focus of the qualitative study. For the growth of performance, qualitative study participants could identify common themes for their development. The first set of themes that answer this sub-question is the experiences they had as individual students. The themes for developing the ability to perform professional competencies are:

- Reflective Process
- Self-Identifying Improvement Plan
- Cyclical – Continuous Improvement Process
- Positioning One's Self in Professional Performance Expectations
    - Experienced a Cultural of Professional Expectation
    - Comparison Process
    - Feedback on their performance

The reflective process of their experiences was present in all aspects of development. The self-identifying of an improvement plan is the process of students identifying their growth areas for professional competencies. The cyclical nature of the professional development curriculum was identified by the study as being a cyclical-continuous improvement plan. It is a direct result of the PBL curriculum. Throughout these experiences, students identified different ways in which they experienced positioning themselves relative to professional competency performance expectations. Their developing awareness of the expectations for professional competency performance was supported by the expectations of the PBL curriculum culture. The awareness was developed as the students went through a comparative process of positioning themselves relative to the observed performance of other students, faculty, and project clients. What was observed was reinforced by the feedback, which they received on their performances through structured activities in the program.

The second set of themes for answering the third sub-question is the PBL program curricular elements, which the participants identified for developing their professional competency performance abilities. Students identified the:

- program's ***Industry Projects*** with the project client interaction and working on teams,
- the PBL curriculum ***Learning Activities*** of workshops, seminars, and student presentations that are focused on developing and assessing the student performance of professional competencies*, and*
- *the* ***Program Culture*** of a supportive environment with expectation and feedback for professionalism,

as the elements of the PBL curriculum that created the experiences for their development of professional competencies.

Primary Question: "In what ways does the Project-Based Learning (PBL) Curriculum Influence the Development of Professional Competencies?"

The sub-question answers build up to develop an answer to the overall primary research question. The ways in which the PBL curriculum influences the development of professional competencies begins with developing the students' working definitions of the professional competencies. PBL participants were able to verbalize professional competencies at a high level and clearly describe their own professional development process.

The PBL curriculum does not develop the importance for professional competencies, but it reinforces the effect that students maintain a high level of importance. The comparative non-PBL group showed a decrease in their importance for individual professional competencies.

The PBL curriculum influences the development of performance of the professional competencies through creating a cyclical process of exploration and reflection, which develops the students' professional identity and their abilities to assess their professional competency abilities. This process leads to the increasing of their performance abilities of professional competencies. The curricular elements of team industry projects, professional competency learning activities, and a cultural expectation for professionalism support this continuous improvement process over the course of the students' four semesters in the PBL program.

9.2. SIGNIFICANCE OF STUDY

In recognition of the many institutions within engineering education, which are exploring the best ways to develop the professional competencies, the results of this study are aimed at numerous decision-makers at institutions with engineering education programs. The results demonstrate the ability of a PBL curriculum to develop professional competencies, specifically the ability to perform. This study confirms that a PBL curriculum is a promising practice for developing student professional competencies. This study identifies the curricular elements, which can transcend all PBL programs for developing these student participants' professional competencies:

- Projects (industry in this study) completed in a team environment with facilitators and clients that foster and reinforce the development of professional competencies.
- Program cultural expectations for professional competency practice in all aspects of an engineering program.
- The importance of embracing the role of defining moments for students in the development of professional competencies. The defining moments are most effective when tied to genuine engineering activities and participant-directed learning activities.

A practice for consideration, from the IRE PBL curriculum, for incorporation in other curriculums, is the extensive learning activities that explicitly define the professional expectations for students and facilitates the student development of them. It is important to recognize the value of spending significant student and program time on these activities. Key program learning activities are the professional development plans (PDP), weekly professional seminars, extensive student presentation with peer feedback, structured, extensive reflection, and the structured team member performance feedback (yellow sheets) from the facilitator. An example performance evaluation is found in Appendix I.

9.3. LIMITATIONS OF THE FINDINGS

The findings have a few limitations. First is the sample size and self-selection of participants. Second is the instrument design and data analysis.

For the quantitative study, the sample size for the PBL participants was only 56 pre- and 32 post-. These were the only participants available during this period of the early years of the program's development. The experiences that each of these students had is fundamentally the same, but through curricular change from the continuous improvement process, students who experienced the most recent version of the PBL program have limited representation in the sample studied.

The sample size for the non-PBL was 108 and 101 respectively. Although it is a reasonably large number for this study, it is limited in that students are only from two regional universities. Also, due to the time constraints, doing a pre- to post-study comparison of the same students was not in the scope of the study. Results would be more conclusive if the study utilized the same students pre- to post-.

For the qualitative study, the sample size of 18 was limited to those who self-selected to participate and had graduated recently relative to the spring of 2015 semester. This was an inherent limitation of the study due to its limited timeframe.

Both instruments were developed or adapted specifically for the quantitative study. It would have been preferable to utilize existing instruments, which had been validated and widely used. Also, it would have been preferable to use a larger Likert scale. Although 5-point Likert scales are commonly found in similar studies, a larger Likert scale would have made the instrument more sensitive and also avoid pushing respondents towards the positive end of the scale (Garland, 1991). That being said, the instruments were sensitive enough to identify several findings, as discussed, and proved to be reasonable tools for quantitatively analyzing professional competency development.

Needing to be addressed is my personal involvement in the study. My involvement brings with it two concerns. First, my personal bias towards PBL as a curricular model for educating engineers. I have been invested in the development of the IRE PBL curriculum. The development process, both of the program and my personal understanding of learning, along with my personal time investment, create a bias towards PBL. Secondly, I am familiar with a majority of the student participants in the study.

Addressing these two concerns starts with the quantitative instruments. They were completed by both PBL and non-PBL to provide a contrast for comparison. Both instruments are based on widely recognized concepts. The *Individual* instrument is based on the ABET criteria as interpreted by students. The *Team* instrument is based on the nationally recognized TIDEE professional development work. In the qualitative study, the bracketing process of identifying my preconceptions and prejudgments was intended to make me cognizant of them as to “bracket” them out of how the interviews were experienced and interpreted.

Regarding my investment in the program, I was an integral part of the initial program ideation, creation, and development. Since the first few years and continuing through the duration of this study, I have had two position changes in my professional career, which have taken me away from a direct instructional role and visible participation in the program. I have continued to be involved in program evaluation. This has resulted in two significant changes. First, I am less vested in the current curricular model, which was evaluated in the qualitative study; consequently, it has less of my personal involvement in its design as compared to earlier years of the program. Second, although I am known to most students in the program and study, I do not have a level of personal relationship that would cause them to want to “give me the answer I desire” any more than any other researcher.

9.4. DIRECTION FOR FUTURE WORK

The limitations of the findings provide opportunities for future work: First, is the continued development of the quantitative instruments. Professional competencies are a long-term focus for engineering education, and having an effective way to assess their development is needed. The development of the instruments would focus on making them more sensitive with a larger Likert scale, continued improvements to the validity of the instrument, and expand its usage with more PBL and Non-PBL students.

Second is to expand the study scope to understand better the development of professional competencies. Looking earlier into the student experience to understand the development of importance for professional competencies would be desirable. The qualitative study should be expanded to understand the experience of students in a non-PBL curriculum. This study identified the lack of growth and an actual decrease in importance in the team instrument for professional competencies; it should be studied further. Although one could speculate as to why this occurred, explaining this will require a qualitative analysis to develop an understanding of how the non-PBL students experience their upper-division program as it relates to their development of professional competencies.

9.5. FINAL SUMMARY

The development of the Iron Range Engineering (IRE) project-based learning (PBL) program and this study were in response to the systemic calls for change in engineering education. Of particular interest to myself as the researcher was the development of professional competencies. This interest was the result of my personal experiences as a practicing engineer in industry, my experience as an engineering educator, and the need for professional competency development being a focal point in most calls for engineering education.

The IRE curriculum was developed to include, at the core of the student experience, a cyclical process of exploration and reflection that develops the students' professional identities and thus increasing their performance abilities of professional competencies. The essential curricular elements for this experience are team industry projects, professional competency learning activities, and a cultural expectation for professionalism that support this continuous improvement process over the course of the students' four semesters in the PBL program.

The key findings indicate the curriculum is successful in influencing the student development of professional competencies. The findings of my colleague, and fellow PhD student, Ron Ulseth, are that it also develops the students as lifelong, self-directed learners. The findings of these two studies indicate the potential for the use of PBL to improve engineering education.

As identified throughout Volumes 1 and 2, change is needed in engineering education, and PBL is recognized as having promising practices for accomplishing this change. This study and its findings serve as further evidence of the ability of a PBL curriculum to positively influence the development of student professional competencies and provides a better understanding of how students experience this development.

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APPENDICES

Appendix A. Pilot Curriculum Description

Authors' description of IRE model at end of one year of model (an excerpt) (Ulseth, Johnson & Bates, 2011).

"THE IRON RANGE ENGINEERING EDUCATION MODEL

The IRE model in the United States addresses the calls for change in engineering education. The primary emphasis is on the development of learning outcomes, contrasted with primary emphasis on coverage of topical material that characterizes many of the engineering programs throughout the world. The learning in the IRE model is 100% project based and is targeted at the development of a technically sound, highly professional graduate who possesses high levels of problem solving ability and has experience in engineering design. In an adaptation of the Aalborg Model of PBL (Figure 1), IRE students combine learning of technical information and professional development with the execution of engineering design projects. A guiding principle for the IRE model is that, throughout the projects, students own the responsibility for their learning through the projects while obtaining the technical and professional knowledge and competencies which have been defined for the program.

Project Cycle

The core of the IRE model is the learning that takes place around engineering design projects. At the beginning or "proposal stage" of each project cycle, students, in collaboration with faculty and clients, develop two plans: a design "work plan" which details the entire execution of the deliverable to the client; and a "learning plan" which addresses professional learning objectives, technical learning objectives, and the learning modes that will be employed to meet the objectives (self-directed learning, peer-directed learning, faculty-directed learning, and external expert-directed learning as well as methods for formative assessment and reflection). Students execute one to two project cycles per semester.

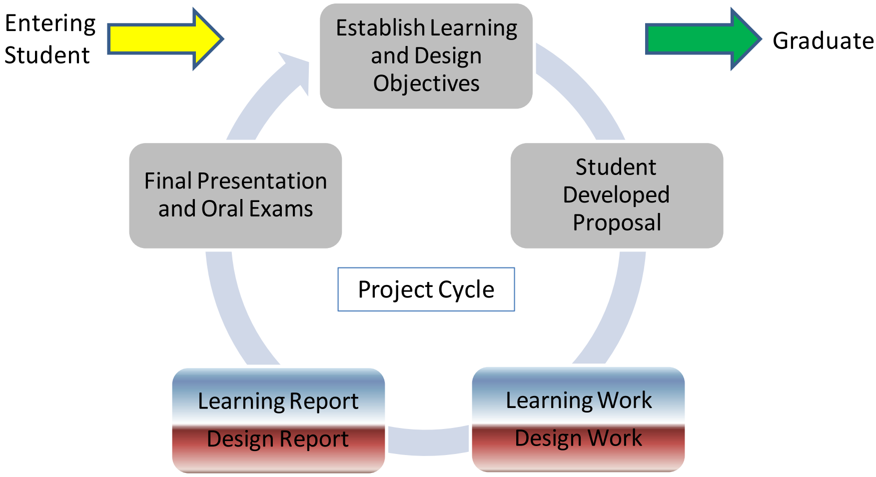


Figure 1. Iron Range Engineering Program Model of PBL: Adapted from the Aalborg Model of PBL (Kolmos, 2004).

Each cycle concludes with the presentation of two reports: a design report for the deliverable and a learning report that reflects the learning process and provides evidence of outcome attainment. In addition to written reports, a student presentation is made to faculty and external clients. The final presentation includes an extensive oral exam in which students show their understanding of technical engineering knowledge and the competencies acquired. At the conclusion of each project cycle, students have a new view of their levels of knowledge and competencies.

Technical Competencies

For each technical competency, assessment is done on a continuum, from novice to expert, using Bloom's modified taxonomy (Krathwohl, 2002). During the student's first semester, her individual starting point is established through working with faculty. In this way, the IRE model recognizes each student's different starting points and empowers all students to build on their strengths and overcome their weaknesses as they navigate their education. Each semester students achieve eight technical competencies. For core competencies (eight mechanical and eight electrical), there is a fixed syllabus. For advanced competencies, students work with faculty to develop a personalized syllabus. In all cases, a technical competency consists of the development of knowledge through deep learning activities (Litzinger, 2011). Upon starting a project and meeting with industry clients, students identify which core and elective competencies best meet their individual and project needs. Some technical competencies are learned early in the semester as necessary background knowledge. Others naturally develop during project execution and are learned later in the semester. To graduate, students must attain "work ready" competency in core and advanced competencies.

Throughout the learning process, students have multiple interactions with faculty, learn through self-study and in peer groups, and tie their learning to their projects. Students regulate their learning through organization of new knowledge, evaluation of quality of learning, and making in-progress changes to learning based on those evaluations. Each week, students meet with faculty in a “Learning Review” to discuss progress, impediments and plans for learning in the upcoming week. Students take oral and written exams, and provide evidence of deep learning for each competency. Students complete course and graduation requirements by exceeding or meeting levels of competencies based on clearly articulated outcomes.

Professional Competencies

At the beginning of the IRE experience, students also identify all of the professional competencies or attributes that are expected of them by graduation. Working with faculty, they gauge their baseline in each attribute. Each semester, faculty provide learning activities in leadership, learning about learning, team work, communication, personal responsibility, professional responsibility and the entire spectrum of executing the design process. Through reflection, personnel evaluation by project mentors, client feedback, peer feedback, and faculty evaluation, students track their advancement towards their graduation goals. At the end of each semester, students write improvement plans for the next semester including specific activities aimed at enhancing their performance.

Through PBL, industry interactions, and significant metacognitive activity, students develop advanced problem solving skills, deep technical knowledge in the fundamentals of engineering, advanced knowledge in selected disciplines, and a well developed set of professional skills such as writing, speaking, project management, leadership, conflict management, and ethical decision making. The expectation is that these experiences will lead IRE graduates to meet the ABET a-k student outcomes (ABET, 2009) at levels much higher than in traditional US programs.”

Appendix B. IRE Student Outcomes and Performance Indicators

Technical Outcomes	Design Outcomes	Professional Outcomes
Tech 1. *An ability to apply knowledge of mathematics, science, and engineering* • Describe concepts in an oral exam • Solve closed-ended problems • Use knowledge in a deep learning activity Tech 2. *An ability to design and conduct experiments, as well as to analyze and interpret data* • Design an experiment to answer a question related to technical work • Acquire experimental data and compare results to appropriate variables • Explain observed differences between model and experiment and offer explanations Tech 3. *An ability to identify, formulate, and solve engineering problems* • Choose and apply appropriate engineering principles needed to solve an open-ended problem • Determine the reasonableness of a solution to an open-ended problem • Evaluate the completed solution	Design 1. *An ability to design a system, component, or process to meet desired needs within realistic constraints* • Accurately report a scoping process for a project in writing and verbally • Conduct the design process iteratively to develop a solution meeting the requirement • Critically judge design solution effectiveness based on project requirements Design 2. *An ability to function on multidisciplinary teams* • Establish a team contract setting team expectations and assign appropriate roles • Analyze effectiveness of the group during the project • Evaluate quality of teamwork achieved and its impact upon satisfying project requirements • Individually contribute appropriately to completion of the team project. Design 3. *An ability to lead, manage people and projects* • Create a team time budget based on a list of tasks within a project • Implement a team course of action to finish all required tasks by a deadline. • Evaluate effectiveness of one's ability to lead, manage people, and manage projects; develop a plan for future improvement	Prof 1. *An understanding of professional and ethical responsibility* • Write professional development improvement plans, semester by semester • Actively participate in multiple outreach activities per semester • Take part in and document regular design project ethical implication conversations • Meet the Professional Expectations of an IRE student Prof 2. *An ability to communicate effectively* • Communicates project details verbally to various audiences • Communicate technical information to student peers • Analyze individual communication effectiveness and develop an improvement plan • Complete "Jobs Package" • Develop Personal Marketing Plan • Evaluate others' writing and

process to determine effectiveness Tech 4. *A recognition of the need for, and an ability to engage in life-long learning* • In learning journal, demonstrates effective learning principles • Develop and communicate personal learning model in a learning journal • Apply Metacognition techniques to improve individual learning in a metacognition memo Tech 5. *An ability to engage in entrepreneurial activities* • Recognizes the financial impacts of the proposed design. • Choose and apply business concepts to products and processes.	Design 4. *An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice* • Document a wide range of acquired technical skills and techniques through the development of a "best works" portfolio of their engineering practice • Document acquisition of and growth in professional skills and techniques through periodic personal performance evaluations • Solve advanced engineering calculations and perform design analysis using modern tools Design 5. *The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context* • Identify and apply contextual knowledge that influences design solutions. Examples include, but are not limited to these: health, safety, environment, global, societal, ethical, moral, legal, financial, human, and lifecycle.	presentations and provide feedback Prof 3. *An ability to work successfully in a diverse environment* • Write PDP goals that show that interacting with others in a professional and respectful manner in all situations is a critical tool for success. • Maintain a daily work environment free from behaviors and speech that cannot be tolerated in an engineering environment. • Demonstrate an understanding of unconscious bias and its implications. Prof 4. *A knowledge of contemporary issue* • Demonstrate awareness of contemporary issues

Appendix C. IRE Project Solicitation Form

Iron Range Engineering
Project Solicitation

Educational Scope:

IRE student projects are meant to serve two purposes: 1) provide engineering students with an experience that enables them to develop project management skill, technical expertise, design experience, and professional competency, 2) contribute, in a meaningful way, to the client by meeting the client's defined need.

Process:

At the beginning of the semester, students and their IRE faculty mentor will meet with the client in a scoping meeting to identify deliverables, constraints, timelines, and resources. At this time, the project team and the client will agree on periodicity and types of communication to take place during the project. After the scoping meeting, students perform background research, complete a scoping document, develop options, design experiments and models to test the options, select an option, and execute the design to meet their client's deliverable needs. Each student spends 15-20 hours per week working on this process. They spend an additional 25-30 hours per week completing their technical and professional learning for the semester. The best technical learning takes place when it is directly related to the team's project. At the end of the semester, the students will have created a significant (often 100+ page) technical document detailing their design process, they will present their technical document, as well as the design deliverables, to the client in a formal presentation.

1. Project description (1 paragraph summarizing project):
2. List of specific desired deliverables at end of project:
    -
    -

3. Anticipated length of project (one or two semesters): _________

4. Suggested number of students working on project: __________

5. Areas of engineering technical knowledge students will need to acquire through execution of the project (e.g. thermodynamics, power distribution, foundation design, etc.)

-
-

6. Contact information for primary contact at your company:

Name: ___________________________________

Email: ____

Phone: _______________________________________

Cell: ____

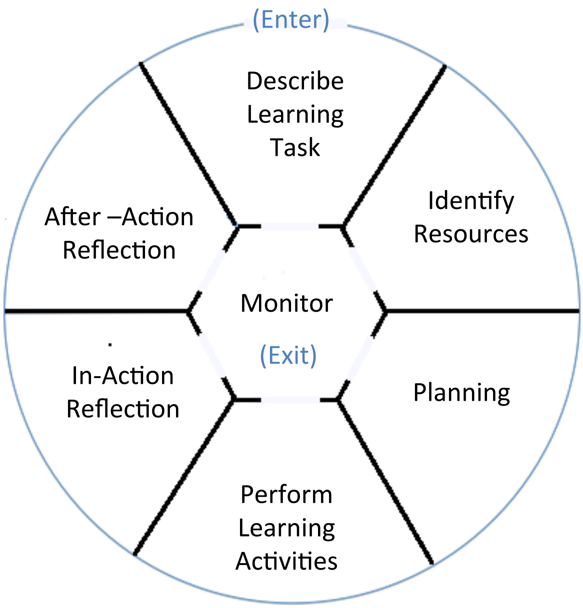
Attributes of successful IRE projects:

- Meaningful and realistic projects
- Clearly defined expectations
- Responsive communication in both directions
- Multiple opportunities for students to spend time on-site learning and interacting with engineers and technicians

.

Appendix D. Professional Competency Instrument

IRE Metacognitive Process



There are two steps to the metacognitive processes used at Iron Range Engineering.

1. Learning Journal
2. Metacognitive Memo

Learning Journal Requirements –

[Due to the importance of these metacognitive activities to the practicing engineer, and in the development of the future engineer, we request you use a learning journal for all of your learning activities.] 1. Prior to learning, write your pre-learning paragraph. Include a sentence or two describing the learning task and a sentence or two

describing the resources you will use.

2. Plan and write down a list of the steps you will follow to achieve the learning task. Make a brief indication of the intensity and speed you intend to bring to this task.

3. Do the learning. This does not have to be recorded in your learning journal. It can be taking notes while reading or in an LC, or solving problems on a white board, or working on a DLA. It is the performing of the activities you do to learn.

4. Perform an in-action reflection in which you write a few sentences summarizing what has been accomplished, make judgments on the speed, estimate % done, and predict the likelihood for success.

5. Write after-action summary. Describe current status of learning task accomplishment, future value of learning, future plans, etc.

* As you move from step to step in your journaling, practice using the monitor questions. Does my plan meet my need? Are my resources adequate? Am I on pace to succeed? Which "room" should I enter next? Etc.

Metacognitive Memo Requirements –

[One metacognitive memo is due at the end of each IRE block. It will address all of the learning you completed during that 8 week period and will be a factor in the grade for each technical competency on which you worked.]

Write in memo form:

Date: (date of writing of memo)

From: (you)

To: (your technical competency instructors)

Subject: Metacognitive Memo (block __, of _______ semester, _____(year))

1. Paragraph 1 – Block Overview (Briefly describe the courses taken including major principles learned and DLA's completed).

2. Paragraph 2 – Learning Journal Use (comment on the extent to

which you used your learning journal to perform the metacognitive tasks: identifying learning tasks, identifying resources, planning learning, reflecting in-action, and reflecting after action)

3. Paragraph 3 – Learning Journal Quality (use the 1-5 scale of 1-deficient, 2-weak, 3-acceptable, 4-desired, 5-exemplary) to rate your use of metacognition. Provide 2-3 sentences of evidence defending your rating.

4. Set goals with action plans for improved use of metacognitive strategies in your next block.

.

Appendix E. Student Outcomes Rubrics

Rubrics for IRE Outcomes

An ability to function on multidisciplinary teams

	Generic Definition of Levels				
	Shows little evidence of desired performance, clearly not acceptable for IRE graduates	Shows some but inadequate evidence of desired performance needed in IRE graduates	Shows moderate evidence of desired performance, minimally acceptable for IRE graduates	Shows strong evidence of desired performance, clearly meeting high expectations of IRE graduates	Shows unusually strong evidence of performance as a skilled professional, exceeding expectations of IRE graduates

Performance Indicator	Performance Levels				
	1 = Deficient	2 = Weak	3 = Acceptable	4 = Desired	5 = Exemplary
Establish a team contract setting team expectations and assign appropriate roles	With limited input from teammates, poorly defines teamwork expectations and few roles, may show strong biases or major flaws in thinking	Without teammate agreement, writes sketchy teamwork expectations, identifies some member roles; overlooks accountability or productivity issues	With teammates, defines reasonable teamwork performance expectations and assigns members roles that fit responsibilities of a productive team	With teammate consensus, establishes individual and collective teamwork expectations, role assignments and accountability for high performance teamwork	With strong teammate buy-in, prescribes clear and detail individual and collective performances, roles, monitoring and review practices to ensure high performance teamwork
Analyze effectiveness of the group during the project	Refuses to acknowledge team problems or cannot see opportunities to improve team performance; unable to identify functioning aspects of team	When asked, can identify problems in team, but unable to identify actions to make improvement; unwilling to take action for fear of upsetting individuals	When prompted, reviews teamwork performance (positive and negative), identifies suitable actions to improve teamwork; slow to take action to improve teamwork	Regularly reviews teamwork effectiveness and its impact on project completion; identifies, implements actions to improve overall performance; is able to deliver critical feedback in a constructive manner	Uses ongoing reflection and scheduled reviews to assess teamwork, define ways to improve individual and collective teamwork skills, and reach high performance; supports the analysis and improvements of other team members creating
Evaluate quality of teamwork achieved and its impact upon satisfying project requirements	Does not identify strong individual or collective teamwork contributions nor identify useful steps to improve teamwork	Poorly defines strong individual and collective teamwork contributions or impacts; does not identify useful actions to improve teamwork	Defines strong individual and collective contributions and their impacts on project; identifies actions to improve teamwork	Documents how strong individual and collective contributions impacted project completion; identifies actions that can improve future performances	Insightfully documents how orchestrated multi-disciplinary teamwork with ongoing reflection and improvement by all enhances performance and project completion
Individually contribute appropriately to completion of team project.	Poor contribution to team completion of project. Did 50-75% of what was expected of the individual in the team plan.	Contributed to team, but not quite as an equal partner. Contributed greater than 75% and less than 100% of what was expected of the individual in the team plan.	Contributes equally to completion of team project.	Contributes equally to completion of team project; made efforts to include all members a equal partners.	Contributes equally to completion of team project; effectively enabled other team members to contribute at a level higher than they otherwise would have.

Rubrics for IRE Outcomes

An understanding of professional and ethical responsibility

	Generic Definition of Levels				
	Shows little evidence of desired performance, clearly not acceptable for IRE graduates	Shows some but inadequate evidence of desired performance needed in IRE graduates	Shows moderate evidence of desired performance, minimally acceptable for IRE graduates	Shows strong evidence of desired performance, clearly meeting high expectations of IRE graduates	Shows unusually strong evidence of performance as a skilled professional, exceeding expectations of IRE graduates

Performance Indicator	Performance Levels				
	1 = Deficient	2 = Weak	3 = Acceptable	4 = Desired	5 = Exemplary
Write professional responsibility improvement plans, semester by semester	Does not identify areas to grow as a professional; does not identify specific growth achieved over time	Identifies vague areas to improve. There are unclear steps to grow as a professional; claims but does not document growth over time.	Identifies areas to improve and general steps to grow as a professional; documents distinct growth over time	Clearly identifies need for improvement and plans specific steps to elevate professional performance; documents substantive growth over time	Monthly reviews and updates own professional goals and progress, plans specific improvement steps, acts purposefully, and documents remarkable achievement over time
Actively participate in multiple outreach activities per semester	Very rarely participates in outreach activities	Each term, engages in outreach activities that include at least 5 hrs of community service	Each term, engages in outreach activities that include at least 7 hrs of community service plus committee service for a professional or college-affiliated organization	Each term, engages in outreach activities that include at least 10 hrs of community service plus committee service for a professional or college-affiliated organization	Regularly engages in, often leads outreach activities; >15 hrs/term of community service; provides leadership for a professional or college-affiliated organization
Take part in and document regular design project ethical implication conversations	Reflection journal does not address actions nor infer consideration of professional and ethical responsibilities related to project	Reflection journal omits mention of professional or ethical responsibility related to project; journal also records some design actions inferring consideration of these issues in project	Reflection journal occasionally mentions professional and ethical responsibilities related to project and related actions that improve project	Reflection journal shows regular discussion of professional and ethical responsibilities related to project and resultant improvements to project	Displays and documents ongoing devotion to professional and ethical responsibilities related to project; compelling evidence of related project improvements
Meet the Professional Expectations of an IRE student	Completes assessment by only checking boxes, self assessment is out of line with team facilitator, not open to constructive feedback	Completes assessment by only checking boxes, self assessment is out of line with team facilitator, open to constructive feedback	Completes assessment, self assessment is in line with team facilitator, open to constructive feedback	Completes assessment, makes statements about performance, is well aligned with team facilitator, open to constructive feedback	Completes assessment, offers specific statements about performance and establishes goals, well aligned with team facilitator, open to constructive feedback

Rubrics for IRE Outcomes

An ability to communicate effectively

	Generic Definition of Levels				
	Shows little evidence of desired performance, clearly not acceptable for IRE graduates	Shows some but inadequate evidence of desired performance needed in IRE graduates	Shows moderate evidence of desired performance, minimally acceptable for IRE graduates	Shows strong evidence of desired performance, clearly meeting high expectations of IRE graduates	Shows unusually strong evidence of performance as a skilled professional, exceeding expectations of IRE graduates

Performance Indicator	Performance Levels 1 = Deficient	2 = Weak	3 = Acceptable	4 = Desired	5 = Exemplary
Communicates project details verbally to various audiences	Writes, speaks, or displays project information (sometimes irrelevant) in ways that mislead, confuse, or fail to inform	Writes and speaks unclearly about some project details; uses language, format, or illustrations in ways that defy or confuse understanding	Writes and speaks understandably about important project details; satisfactorily uses language, format, and illustrations to aid understanding	Writes and speaks clearly and concisely about essential project details; competently uses language, format, and illustrations to aid understanding	Writes and speaks articulately, concisely about essential project details; uses language, format, and illustrations very professionally to inform and motivate
Communicate technical information to student peers	Incompetently presents technical concepts (equations, methods, applications) to peers; leaves others confused, doubting correctness of information	Unclearly discusses technical concepts (equations, methods, applications) with peers; does not aid but may confuse understanding of others	Understandably discusses technical concepts (equations, methods, applications) with peers; reinforces technical knowledge of others	Clearly, competently discusses technical concepts (equations, methods, applications) with peers; enhances technical understanding of others	Proficiently explains, engages peers actively in discussion of technical concepts in context; inspires, deepens rich technical understanding of others
Analyze individual communication effectiveness and develop an improvement plan	Fails to self-assess communication skills; does not identify improvement goals, plans, or future reviews of these skills	Vaguely identifies areas to improve without specific steps or timeline to achieve or monitor improvement	Identifies areas to improve with limited steps and timeline to achieve and monitor improvements	identifies specific areas to improve; defines plan with methods, target, and review dates	Identifies specific communication skills to improve; includes methods, timeline, and evaluation method to achieve desired skills
Create Personal Marketing Plan	Does not complete a personal marketing plan; or completes a plan with fewer than three Knowledge, skills, & abilities (KSAs) which are vaguely stated; goals are missing or very vaguely stated.	Ineffectively communicates a poorly developed personal marketing plan; fewer than 5 KSAs are identified or goals are vaguely stated. Little to no action plan is stated.	Communicates a fairly well-developed personal marketing plan. Several relevant KSAs are clearly identified. Goals and action plan are vaguely stated.	Communicates a well-developed personal marketing plan. Several relevant KSAs are clearly stated as well as a realistic action plan to achieve goals. Provides some constructive feedback to peers.	Effectively communicates a well-developed, high-quality personal marketing plan with several desired KSAs substantiated by evidence; SMART goal action plan is stated; actively leads others to do the same.
Complete Jobs Package	Reflection indicates basic participation in package. Few details are included and low level of understanding indicated.	Reflection indicates jobs package was completed. Some details are included with basic indication of future use of knowledge from process.	Reflection shows active participation in jobs package, including detail and an adequate writing style; plans for improvement and future use are indicated.	Reflection shows engagement in jobs package, including clear detail and a good writing style. Plans for future use are clear and make sense in the entry context.	Reflection shows engagement in jobs package, including incisive detail and a strong writing style. Plans for future use of knowledge gained are clear and personal.
Evaluate others' writing and presentations and provide feedback	Incomplete, inaccurate, superficial, disrespectful, and off-target review of the following:	Incomplete, inaccurate, superficial, off-target review of the following:	Mostly complete and accurate, minimally acceptable review of the following:	Complete and accurate, acceptable review of the following:	Complete, accurate, highly detailed, exceptional review of the following:

Appendix F. Example Reflection Journal

Reflection journals contain weekly reflections. This excerpt contains week 1 and 15 reflections for a student from their third semester at IRE.

Week 1 (Aug 24)

Self-directed learning
What does self-directed learning mean to you? To me, self-directed learning is the ability for someone to figure out what they need to learn, be able to acquire that knowledge, and then be able to apply it. It is about taking the initiative for your own learning goals/objectives without someone else being responsible for making sure you are learning what you are supposed to. I also think it involves being aware that learning is a process that involves actual planning instead of trying to jump straight into a solution. Going straight to a solution work for a particular problem/goal at hand, but ends up being much more hollow and less likely to stick long-term than going through a monitored process.
On a scale of 0-5 describe how ready you feel to be the level of self-directed learner that you will need to be after graduation? __4.25_____ Why do you choose this score? After having a couple months working as a practicing engineer, I feel confident giving myself this score because I have been able to demonstrate an ability to take on new projects/learning and obtain successful results. A perfect example is the very first task I was given at work: figuring out how the CAN communications worked on an electronic control module. Instead of jumping right in with no idea what I was doing/looking for, I spent a couple days doing research into what CAN communication was and reading datasheets for the module. When I felt comfortable enough to start I ran into a few problems, but I looked back on my notes from research and figured out what was going wrong and how to fix it. I am very proud that I overcame the admitted urge to ask for help and went back to the tools we worked through at IRE. However, I do see areas where I could improve to help me even more as I continue my career.
In what area of self-directed learning would you like to improve the most? I think the biggest area I could improve in is documenting the whole process instead of just taking notes from resources or test results. I fully understand the importance of documenting the whole process of learning for better retention, but it is tedious, time consuming work and I have a natural tendency to want to start working on a solution. After spinning my wheels with the CAN communication project detailed a little above, I really forced myself to take a

step back and evaluate the entire situation. I then started documenting everything I could and found that I was gaining a much better idea of the problem and the whole system. Taking this more focused approached definitely helped me reach my goal quicker than jumping into a solution, even though that may not seem initiative in the beginning.

What steps might you take to achieve this improvement?

The main step I need to take is to realize that I'm not expected to know everything right away and that it is acceptable/encouraged to take a step back and go through a process for learning more robustly. I certainly feel the pressure of being the new guy and thinking that I should be able to do whatever is asked of me right away, but if I can just go through the self-directed learning process I know there isn't much I can't figure out.

Graduation Requirements

On a scale from 1-5, give your understanding of the IRE course requirements for graduation. ______5______

Why do you choose this score? (If high, why? If low, why?)

I gave myself this score because I know exactly what requirements I have left to graduate and I am on track to meet those by the end of the semester.

What questions do you have that, when answered, better help you understand these requirements.

I don't really have any questions about requirements, but I do need to have some communication with Becky to make sure the administrative side is good to go.

What steps will you take to get these questions answered? When?

I will be emailing [redacted] to start that conversation after I finalize the syllabi for my remaining classes (hopefully this is done by the end of this week). As long as the computer science based classes I'm planning to take count for advanced electrical, I should have no problems.

Week 1 - Third Reflection (If not using this reflection, delete the page from the journal)

Describe the event, experience, etc. that you wish to reflect on.

During my first few weeks at DMR, I was put with another engineer to get an understanding of what types of things I'd be doing. The project he was working on had gone through numerous delays and was way behind schedule for getting these parts to the point of being sold. To get an understanding of where the issues

were occurring, management created a spreadsheet to track each unit's movement to different areas (testing, troubleshooting, repair, etc.) It was becoming apparent that the bulk of the issues were with the programming/tester that the engineer had designed and it was showing on the spreadsheet. To take some of the heat off himself, he started running units through the tester and if he found any failures (even if we couldn't be sure they were true failures and not due to shortcomings with the tester) they were sent to troubleshooting. This created tension between engineering and troubleshooting because they were spending a lot of time looking for failures that really weren't there just because our engineer didn't want to look bad. Naturally, it was eventually discovered that the tester was to blame and it made the engineer and the department look bad.
What did you learn? I've thought about this situation a lot, because even though I refused to do the same thing when I ran units at that station, I still felt complicit in what may not have been technically unethical, but certainly lacked integrity. I was really in no place to question him (because he was able to justify why he was doing it) but it felt dirty. Eventually it worked out from a production stand point, but I'm not sure that engineer's reputation can fully recover. From this experience, I have learned that I would much rather take the blame and heat from management for issues with my work instead of trying to pass it to someone else. I guess I always knew that, but this experience really confirmed it.
How will you use this learning in your future? I used the learning from this experience immediately (even while it was still going on). Instead of dumping a unit onto troubleshooting, if I had a problem with something I would bring it to them and see if they had seen a similar problem and been able to fix it or if it was something that was almost certainly the tester. Doing this made them a collaborator instead of a scapegoat and I was able to build a good working relationship with them and was able to work with them to solve a couple of the common problems we were seeing with the units.
What questions do you still have? This happened over two months ago now but I still think about it from time to time. Was what the engineer was doing actually unethical? I guess there are more details to the situation than I described here that would lead me to say it wasn't, but integrity and reputation are far more important to me than catching some heat from management. I also wonder if I should have done more than just refusing to do it myself. Again, I was so new and there were other details to make me think I did all I needed to do, but I will be better prepared to handle a situation like this if it should happen again in the future.

Week 15 (Nov 30)

Outreach Summary
Briefly describe the outreach activities you completed this semester: I am disappointed to say that I haven't done a single outreach activity this semester. I honestly didn't even think about it throughout the semester until I saw the heading for this reflection entry. Between starting my new job, trying to finish up my degree, and having a busy two year old at home, free time has been hard to come by. It's not to say I couldn't have found the time though and really should have. I feel like I can make a reasonable excuse for not getting much done, but there is always an excuse for being busy. I always enjoyed participating in outreach activities in the past and think it is important for everyone to give back however they can so I'm not happy about having to admit to doing nothing this semester.
What value do you feel you provided in this service? Obviously, I can't really speak to any value I provided this semester, but I think there is always value when people volunteer their time to help others. Even if it is something small, it is still valuable and can get you in a routine of seeking out other opportunities to give back.
Give an honest statement about your personal beliefs on the value of engineers providing service to their communities? Honestly, I've always felt that it is a little weird that community outreach is part of your grade as engineering student (at least at ICC and IRE). I think everyone has the responsibility to give back when possible, but having it be a required part of the curriculum cheapens the gesture. Recognizing that community outreach shouldn't be about the volunteer to start with, it should really be something people do because they want to help and not to get a couple of hours to add toward a grade. I really like that the engineering program is often involved in so many activities, but I think you can still can volunteers (the genuine ones) even without the reward of a grade.
How could the IRE outreach program be improved? I really haven't been that involved in the IRE outreach program so it's hard to say. All the outreach activities I have done were things I found on my own and had interest in. It seems like there are plenty of events that come through the program for students to be part of and I think that's all you can really ask from the program.

Week 15 - Second Reflection
Describe the event, experience, etc. that you wish to reflect on. I thought it would be fitting for my final reflection entry at IRE to be on the reflection process. I will fully admit to being a skeptic on the value of reflections when I first started at IRE. I spent so much time in a traditional learning environment and thought spending valuable school time writing reflections instead of studying or doing homework was a waste. However, I have come to see the true value of them if they are taken seriously and done right.
What did you learn? While I think I could make better use of the reflection journal (namely by going back to look at previous entries once in a while), I still think I've developed into an effective reflector. I find that writing the entries is easy because I usually write about the things I think about. Writing them down provides structure to all the thoughts I have about a particular subject and can really help me review the things I've learned to make them stick. The key to getting any value out of the reflection process is go into them thinking that they provide value.
How will you use this learning in your future? Even though I think I've gotten value from the reflection journals I've done at IRE, I'll be honest in admitting I'm not really sure I'll keep it going after I graduate. I think the principles of a good reflection will stick and that I will do them automatically in my head, but I may not keep writing them in journal form. I do think that it is better to write them for the reasons I mentioned above, but I know me and I'm pretty sure I won't make time for the journal. It mostly goes back to the limited free time I have (an all the other things I want to do with it). Still, being aware of the metacognitive process for reflecting on events/learning is the most important aspect to take away and I'm positive I'll hang on to that.
What questions do you still have? I think it would be interesting to see how many former students still actively reflect on events or on the things they learn. I'm sure that with all the focus on it at IRE that at the minimum they do it on a subconscious level, but actively reflecting (consciously reflecting) may be different. Again, I think I will take the process with me (even if I don't take the journal) and I think that's probably true for the majority of IRE alums.

Appendix G. Example Professional Development Plan (PDP)

Below is an example section from a student professional development plan for the *function on a team* student outcome. Students complete a section for each of the IRE student outcomes.

Initial Evaluation	At this time, I would evaluate myself 4.0 out of 5. While I think I left the end of last semester at IRE with a higher score than this (teamwork was an area I felt I made one of my biggest improvements in and one of the highest scores I received on my Yellow Sheet evaluation), starting fresh at DMR I think I have more room for improvement as I continue to meet and work with more people at the company and figure out how things typically operate. Being the "new guy" to the company, functioning on the project teams is something I've been consciously trying to be active with because I want to make a good first impression with my coworkers that I'm working with for the first time. Even in the first two months with the company, I've been able to identify that communication between the members of the team is an area that could be improved. Because of that, I think that in order for my personal evaluation in this category to improve, I need to work to improve the communication of the next project team I am a part of.
Goals	1) For the SAM project team I'm on, learn what each of the other members needs to do to meet their individual goals for the project. 2) Check in with each team member at least once every two weeks (outside of design review) to see how their part of the project is going and make sure they aren't waiting on me for anything.
Action Plan	Since this project is just starting, the first thing I need to do is find out who from each department is actually on the team. To do this, I'll talk with the other engineer on the team who has been setting up the Gantt chart and ask who else he has been working with. Next, I will go to each of the members individually and ask them "what would need to happen in this project to make it successful for you?". I will take notes of their response for later reference. I will start checking the Gantt chart for this project every Monday to have an idea of what each member is anticipating to do that week. Lastly, I will stop by for a quick conversation with each member toward the end of every other week (late Thursday/Friday) to see if there's anything they need from me.

Mid-term Evaluation	At this point in the semester, both of the goals for this category are on track. I have made an effort to gain an understanding of the roles of everyone else on the team by tracking all the progress being made on the Gantt chart. We have also set up brief, weekly meetings for this project to make sure everyone has everythign they need to progress through the project. These weekly meetings have been very beneficial as we have discovered a couple of issues that could have caused setbacks and may not have been found through the weekly design reviews. Because we feel that there is value in these meetings, the plan is to continue them throughout the remainder of the project.
Final Evaluation	At the end of the semester, I would evaluate myself as a 4.5 in this category. I have been working very closely with all the department representatives for the SAM project. Since the abrupt departure of the engineer who was serving as the project lead, I have done my best to step into that role and take on as many of those responsibilties as I could. At this point in the project, I have worked most closely with the technician who is in charge of building the test fixture so that my software matches with what he is wiring in the hardware. After some minor troubleshooting, we had a working tester that was put through quality's g=Gage R&R. For this, I had to work closely with the quality rep to make sure all the requirements for the test were being met. I am proud to say that the SAM project passed Gage R&R on the first try (something I've yet to see happen with the other projects that have launched since I've been there). At this point, I'm working closely with the process engineer to develop a work instruction for the operators to use when the tester goes into production. I have also done work with the production side (mainly the operators) to train them in on the process and get feedback for design improvements. We did miss our initial deadline, but we are making really good progress and we should be able to launch less than two weeks later than expected.

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Appendix H. Interview Protocol

Interview Protocol for "What is the professional development trajectory of students in the new project based learning (PBL) curriculum?"

Date:	Location:
Interviewer: Bart Johnson	Interviewee:

Instructions: Thank you for agreeing to this interview as part of a study looking at the student professional development trajectory in a PBL curriculum. This is part of a two-part study looking at the student learner in the PBL curriculum at Iron Range Engineering. The other part of the study focuses on how students develop as self-regulated learners. Any information you share in this interview is confidential and your individual responses will not be shared with anyone. You will be asked to elaborate or expand upon responses in order to gain as much information from your answers.

During this interview, we will record the interview, if you agree, and will make notes on paper about your responses. The transcriptions and notes will have no identifying information associated with them. After transcription the audio recordings will be deleted. Until such time, the recordings will be kept secure and made only available to the researchers listed below.

If you decide to participate in this research, your participation is completely voluntary and you are free to skip any question. At any point you can choose to end your participation. Again, if you decide to participate, you are free to stop your participation at any time without penalty. Your choice to participate or not will have no effect on your relationship with Minnesota State University, Mankato. Your choice to participate or not will have no effect on your grade in any course.

Do you acknowledge your voluntary consent to this interview?

Are you at least 18 years of age?

Please state your major and gender:

Initial Question: Which professional skills are important for an engineer? Why?

[Follow up: Have you thought about <time management, personal responsibility, professional responsibility, communication, teamwork, …>? (Choosing one(s) the student didn't include if they do not bring up any or many.)

Question A: When and where did you learn the importance of professional skills for an engineer?

Question B: Which professional skills are your strongest? Why? Please give an example of each.

Question C: Which professional skills do you need to keep developing? Why? Please give an example of each.

Question D: Describe how you experienced the development of your ability to perform professional skills.

Question E: Thinking back specifically on your experience in the PBL program, which elements of the PBL curriculum caused growth in your professional performance ability?

Any closing thoughts or comments on your professional development?

Thank you ___________ for participating in this study. Your answers are greatly appreciated. They will help increase the knowledge of the student professional development trajectory in a project based learning curriculum.

Appendix I. Iron Range Engineering Performance Evaluation “Yellow Sheet”

Below is an example evaluation sheet completed by a facilitator for a student.

Iron Range Engineering Performance Evaluation

The following sections are to be completed by the Faculty Mentor					
Performance Factors	**Poor**	**Needs Improvement**	**Effective**	**Highly Effective**	**Outstanding**
Work:					
Quality					X
• Work product is complete, thorough, accurate, neat and well organized	Comments: Luke lead the software development of a new test program. His software program was very well organized and easy to follow.				
Quantity/Volume					X
• Uses time efficiently • Takes on and completes a fair amount of work on team projects	Comments: Luke's level/quantity of work completed this session was equivalent to an experienced engineer from OMR. He exceeded the expectations for a college student.				
Professional Expectations:					
Responsibility				X	
• Reads all communications promptly and responds accordingly • Contributes to team deliverables and development	Comments: Luke responds very well to emails and one on one questions and his opinion is very valuable. Communicates very well with team. Could work on being more vocal and expressing opinion in group settings				
Promptness				X	
• Arrive at all meetings and class periods on time • Meets all deadlines	Comments: For all daily & weekly team meetings Luke is on time. Meets deadlines when technically able to when challenges arise notifies others. Very few examples of being late for meetings				
Representation				X	
• Dresses and grooms appropriately • Speaks professionally, free of vulgarities, and with appropriate grammar • Acts ethically in all respects • Continually seeks to improve	Comments: Luke represents the company and the team very well in meetings and on the floor. The production employees have a high opinion of him.				
Respectfulness					X
• Treats all others with respect • Maintains a positive attitude	Comments: Luke always takes a positive/realistic attitude toward challenges. He will give a true status update but yet be positive with challenges in front of him.				
Inclusiveness					X
• Works hard to create an environment welcoming to every person • Does not take frustrations out on others	Comments: Luke could have become very frustrated with some people he was working with (when others did), but he ~~was~~ treated everyone very respectfully. Everyone enjoyed working with him.				
Helpfulness				X	
• Willing to assist others inside and outside IRE • Gives proactive feedback to others	Comments: As time allowed Luke was willing to help me on projects or jump on different tasks even though he had his own projects to work on				
Accountability					X
• Takes ownership for mistakes • Acts safely • Leaves every workspace and common area clean and organized	Comments: Luke's work desk and engineer lab area are kept in a neat order. He doesn't have papers spread out all over his desk. He will be an example to others on the team going forward.				

The following sections are to be completed by the Supervisor:

Performance Factors	Poor	Needs Improvement	Effective	Highly Effective	Outstanding
Professional Skills					
Leaderships Skills				~~X~~ X	
• Provides guidance and direction • Inspires teamwork; sets standards, communicates expectations, gives constructive feedback and delegates work and authority appropriately • Promotes creativity independence; acts as a resource and an example • Resolves conflict fairly and promptly	Comments: Luke did an excellent job leading others as needed to help complete his tasks. He wasn't given any opportunities to resolve conflict, but I think he will handle it. He will be given more opportunities for this going forward				
Communication Skills					
Oral communication skills					X
• Ability to express thoughts clearly • Clear organization of message • Calm, confident voice • Good body language and eye contact	Luke was challenged to communicate in several forms from one to one, within the engineering team and to complete office staffs. In all cases it was very well done and received.				
Written communication skills					X
• Ability to express thoughts clearly • Free of grammatical or spelling errors • Strong, professional voice • Good organization	Comments: All documentation and emails received and reviewed from Luke were very clear with no grammatical errors and easily understood.				

The following sections are to be completed by the Faculty Mentor:

OVERALL RATING	Unsatisfactory	Needs Improvement	Effective	Highly Effective	Outstanding
				~~X~~	X

Additional Comments: (Faculty Mentor) **Include Goals and Objectives.**

- Luke has a lot of potential going forward both with his technical and leadership capabilities. He will need to continue to use his learning methodologies from IRE as he faces new challenges. The one potential opportunity for growth for Luke will be in developing the skill and ability to discuss/present his opinions when they may disagree with others.

[redacted] *discussed the appraisal with their faculty mentor on the date signed.*

12/2/15
Date

12/2/15
Date

PERFORMANCE RATING DEFINITIONS	
Outstanding	Consistently exceeds expectations; distinguished performance.
Highly Effective	Frequently exceeds expectations.
Effective	Meets expectations of position in a fully acceptable manner.
Needs Improvement	Meets some expectations but needs improvement in some areas.
Unsatisfactory	Performance is substantially below expectations.

Appendix J. Co-author Statement

Co-author statement in connection with submission of PhD thesis

With reference to Ministerial Order no. 1039 of August 27 2013 regarding the PhD Degree § 12, article 4, statements from each author about the PhD student's part in the shared work must be included in case the thesis is based on already published or submitted papers.

Paper title: *Study of Professional Competency Development in a Project-Based Learning (PBL) Curriculum*

Publication outlet: PhD Thesis

List of authors: Bart Johnson, Ronald Ulseth,

PhD student: Bart Johnson

Scientific contribution of the PhD student (all participating PhD students) to the paper:

- **PhD student:** The PhD student and the co-author co-wrote Volume 1 of this thesis. The PhD student independently authored his own Volume 2. Volume 1 is the theoretical & historical background of work that led to our own individual research work. The co-authorship will be acknowledged at the beginning of each shared chapter in Volume 1 and in the table of contents.
  - In chapter 1 there are 6 sections. The PhD student was the lead writer on sections 1.1, 1.2, & 1.3.
  - In chapter 2 there are 5 sections. The PhD student was lead writer on 2.1 & 2.4 & co-writer of 2.5.
  - In chapter 3, there are 7 sections. The PhD student was the lead writer on 3.5 and 3.6.
  - In chapter 4, there are 9 sections. The PhD student was the lead writer on 4.4-9.

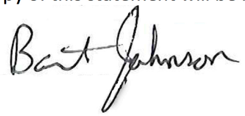
  Lead writer corresponds to having done the majority of the background research, planning on a section, and edit work. In all cases, each person provided section development contributions and edits on the work of the other author.

  Volume 2 is the research work of this thesis and was completed independently, in its entirety, by PhD student.

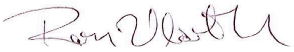
- **Co-author (also a PhD student):** The co-author equally contributed to the theoretical & historical background work of volume 1. Volume 1 has four chapters.
  - The co-author was the lead writer on sections 1.4, 1.5, and 1.6.
  - The co-author was the lead writer on sections 2.2 & 2.3 & co-writer of 2.5.
  - The co-author was the lead writer on sections 3.1-4 and 3.7.
  - The co-author was the lead writer on sections 4.1-3.

  Upon completion of volume 1, the co-author completed, independently, the research and writing of his volume 2.

A copy of this statement will be included in the appendix of the thesis.



Signature, PhD student



Signature, co-author

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